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May 2024

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ISSUE 26
Supportive communities

WELCOME

Although sisters Abigail and Donna Otchere were studying in different fields and at different stages of their education, they were both feeling isolated and in need of support. "We decided to call each other every night and motivate each other with a pep talk," explains Donna. This simple, yet powerful, sisterly act inspired them to help others through SiSTEM UK (p 04), the "vibrant" and "beautiful" community they formed to support girls and women in STEM.

With the same aim of supporting others to aspire and achieve, Rachel Ryan is a proud member of the Stemette Futures Youth Board (p 52) in the UK. Having grown in confidence through a role where she is helping others, Rachel describes the Stemettes Society as "a supportive, inspirational environment".

Professor Gilles Comeau, of the University of Ottawa's Music and Health Research Institute, highlights how music can build communities, connecting people and supporting physical and mental well-being (p 90). He is determined that everyone should have the opportunity to engage with music and benefit from musical interactions.

Which communities are you part of? Who supports you – and who could you support?

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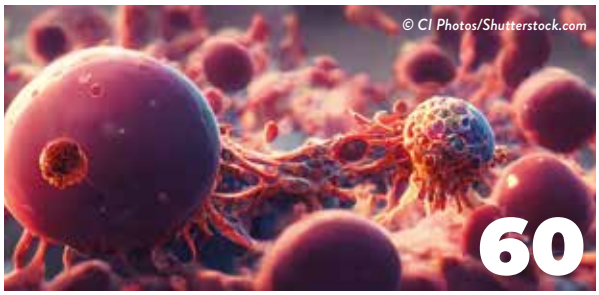

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04

Sisters supporting STEM

SISTEM UK

Having kept each other motivated through their degrees, sisters **Dr Abigail Otchere** and **Donna Otchere** know the power of encouragement and sharing stories. Their own experiences have led them to form **SiSTEM UK**, inspiring and supporting girls and women in STEM.

Where does your passion for STEM come from?

Donna: Curiosity. I was really interested in maths when I was younger, and I was very creative. I wanted something that combined both my interests, and engineering came up through a Google search! Having studied mechanical engineering, I'm now studying for my PhD in gender equity in STEM.

Abigail: I was really excited about science at school, and that was because my science teacher made it intriguing and engaging. She would even make up dance routines to help us understand complex information. I was really interested in diseases and learning about what happens as we grow old; I've always wanted to find the answers to difficult questions. I studied biomedical science, followed by neuroscience, and now work in medical communications.

What motivated you to form SiSTEM UK?

Donna: SiSTEM UK was formed through our struggles. I was doing my mechanical engineering degree, and Abigail was doing her PhD. We were in two different fields, but facing the same struggles of feeling alone and isolated. We decided to call each other every night and motivate each other

Dr Abigail Otchere and Donna Otchere working with primary school students © SiSTEM UK

with a pep talk. That would give us the energy and momentum to get back into the classroom and face tasks the next day. Once we graduated, we realised it had been that support system – the two of us – that had got us through our degrees. We wanted to give that support to other people, and so we started an Instagram page.

Abigail: We wanted to highlight different types of careers in STEM and to show girls and young women that you can look like us and be in STEM. You can have other interests and still be in STEM! And that turned into this amazing community of SiSTEM UK.

What barriers are faced by women in STEM?

Abigail: For me, retention of women in STEM is as as important as, or even more important than, getting women into STEM in the first place. A lot of women are going to university to study STEM subjects but then leaving STEM fields afterwards. We really want people to feel they have a safe space, that they belong and that they are capable. I think for women in particular, imposter syndrome comes into play, and you can feel out of your depth. Also, as they grow older, women often need to have a flexible job – not having that can cause retention issues.

What does the SiSTEM UK network look like in practice?

Donna: We support girls from age five to professional adults. We have learnt that young girls are not always introduced to STEM subjects early enough. We support girls of a range of ages by running workshops in primary and secondary schools. We show them that you can look like us and be in

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A primary school student taking part in a SiSTEM workshop © SiSTEM UK

STEM, and we tell them our stories. We didn't have the easiest of journeys into STEM, and didn't have the best grades, but we were able to break through the barriers we faced. That inspires them because they can see themselves in us – representation is important.

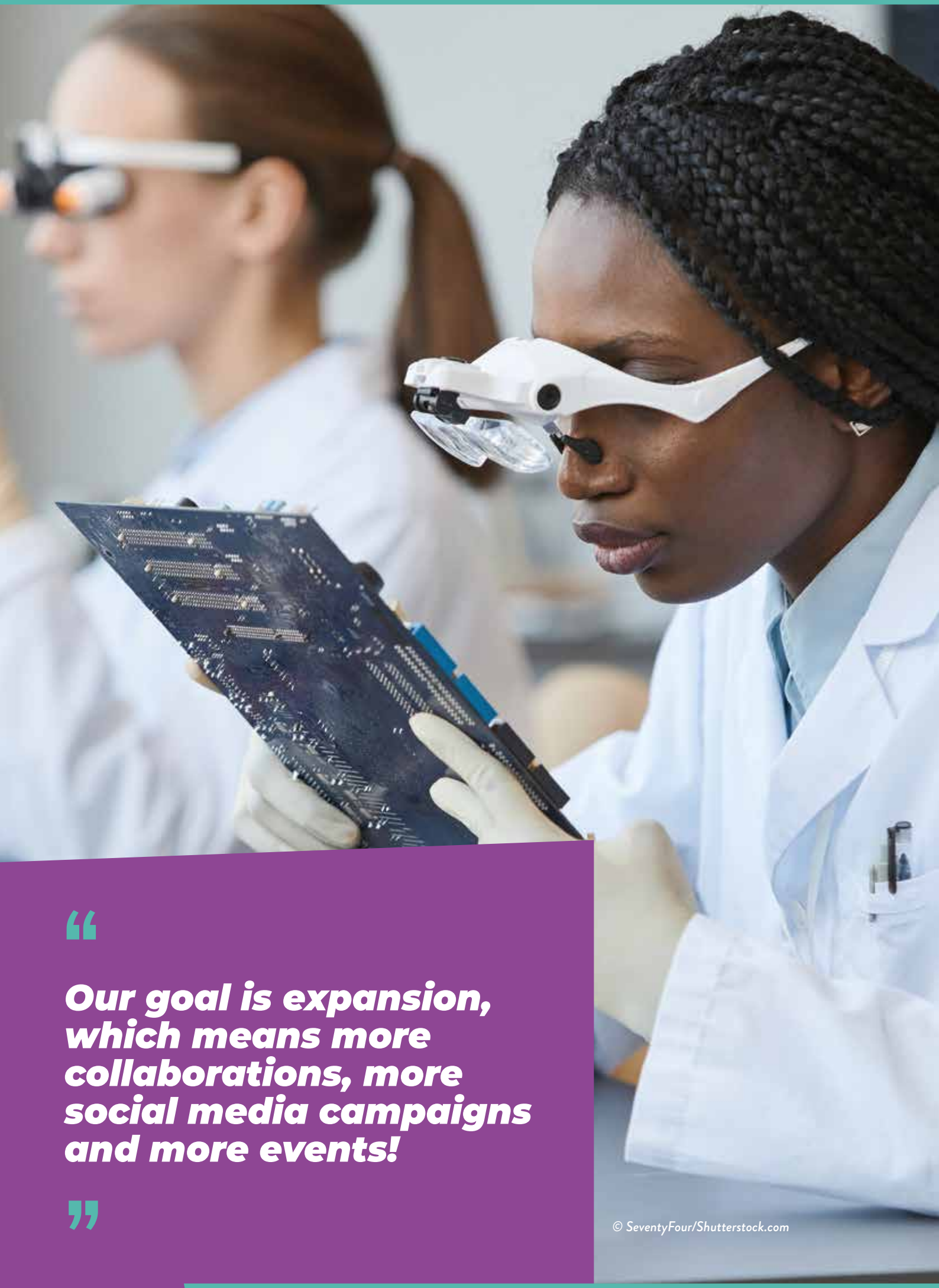
We run a confidence workshop because there is a confidence gap between boys and girls, which prevents girls from excelling. We teach them that confidence can be learnt – we didn't start off being the most confident of people, but here we are!

Abigail: Another of our workshops explains different STEM careers. We show students that to be a scientist, you don't have to be in the lab. You can work in tech, in business; science is everywhere. And science is progressive, so there are many new, cool jobs becoming available.

We also run networking events, where we try to change the narrative and move away from the corporate idea of networking. We make our events relaxed, so girls and women can feel comfortable, have fun and celebrate, as well as network, with each other. We also work with companies to educate their workers on diversity and inclusion.

> **"We really want people to feel they have a safe space, that they belong and that they are capable."**

Abigail and Donna working with college students © SiSTEM UK



> ***Our goal is expansion, which means more collaborations, more social media campaigns and more events!***

Donna Otchere and Dr Abigail Otchere leading a SiSTEM UK workshop © SiSTEM UK

What is your advice to anyone who does not see themselves in STEM?

Donna: We believe it's always important to share stories – our stories and the stories of women who've gone before us. We highlight that you might not be getting the best grades at school at the moment, but that doesn't mean that STEM is not for you. You can still succeed and have a great career. It's not that you can't do it, it's just that you don't believe in yourself enough to do it.

Abigail: From my personal experience, I can think of times when I didn't apply for a job and I didn't go for an opportunity because I thought that they wouldn't pick me. I disqualified myself before even trying. And that's what we really try to encourage women and girls to see – that we can be our own worst enemy at times because of what we have learnt to 'expect'.

Who is SiSTEM UK collaborating with?

Donna: We've always said collaboration is key. We can only do so much, and the barriers facing women in STEM are not going to be broken by just Abigail and me! We need to work with more people to be able to make effective change. One organisation we work with is **In²Science**, which has been phenomenal for our progress in schools. Through them, we're able to reach more schools at a faster rate. Our collaboration with In²Science is enabling us to help train their ambassadors, getting more people into schools, in front of girls. Collaboration helps us spread our message faster.

Abigail: We're going to schools that are close to our hearts. We've gone all over the UK, but our focus has been in the Lambeth area of London. We're looking to spread our reach; training ambassadors will help us to do so. And each ambassador has their own story. Many are university students or early career scientists, and we see their confidence increasing.

What have been the highlights for you so far?

Abigail: For me, it's meeting young people. Before a workshop, you can see they're quite shy, 'in their shell'. And at the end of it, they've broken out of their shell. The room becomes a safe space where everyone celebrates each other. Just to watch that is amazing.

Donna: You see yourself as that young girl – and now we're giving something back to other people. This year, we're celebrating SiSTEM UK's two-year anniversary. In a short space of time, we have already made a positive impact. We've proved to ourselves that we can do it, and we're incredibly proud of that.

What has SiSTEM UK got planned for the summer?

Abigail: We are going to be holding two main events in August 2024. Firstly, we'll be running our annual 'big picnic', which is a collaborative picnic event in London where young people and working professionals will come together as women in STEM. It's called the big picnic as it's a collaborative initiative with different, mainly female-led, organisations from the STEM space. It gives people the chance to meet others from different communities. It's a lovely day, showcasing organisations that are out there and showing women and girls that they belong in the STEM community.

Donna: And then we have our brunch, which is for over 18s, for professionals and students to get dressed up, get together and network in a more relaxed way. The brunch includes a panel of fantastic women who share their stories. We're excited about our events because they're opportunities to see our community coming together in one place, sharing advice and support.

What are SiSTEM UK's long-term goals?

Abigail: Reaching more women and girls. Our goal is expansion, which means more collaborations, more social media campaigns and more events!

Donna: We also need to train more people to support our work. We have an internship programme, where we train our volunteers in different areas such as social media and blog writing. Our aim is to give girls and young women the chance to do what they are passionate about.

How would you sum up the SiSTEM UK community?

Donna: Vibrant.
Abigail: Beautiful!

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- **linkedin.com/company/sistem-uk**
- **sistemuk**
- **sisstemuk@gmail.com**

Can we reveal Earth's secrets by dating faults?

Understanding the Earth's geological history is crucial, not only for revealing its hidden evolutionary past but also for predicting future events. **Dr Dawn Kellett**, a research scientist at the **Geological Survey of Canada**, focuses on methods to accurately determine the ages of geological faults, providing invaluable insights into Earth's geological evolution.

Dr Dawn Kellett

Research Scientist, Geological Survey of Canada, Natural Resources Canada. Adjunct Professor, University of British Columbia, Queen's University, Dalhousie University and Saint Mary's University, Canada

PROFILE

Fields of research
Structural geology, tectonics, geochronology, thermochronology

Funders
Government of Canada, Natural Sciences and Engineering Research Council of Canada (NSERC)

Talk like a ...

geochronologist

Decay — the process by which unstable isotopes transform into more stable isotopes over time, emitting radiation in the process

Earth's crust — the outermost layer of the Earth, consisting of solid rock that forms the planet's surface

Isotopes — different forms of the same chemical element, which have the same number of protons but different numbers of neutrons in their nuclei, affecting their mass

Mass spectrometry — a technique used to analyse the chemical composition of a substance by measuring the masses of its individual atoms and molecules, and their isotopes

Minerals — naturally occurring substances with a specific chemical composition and crystal structure

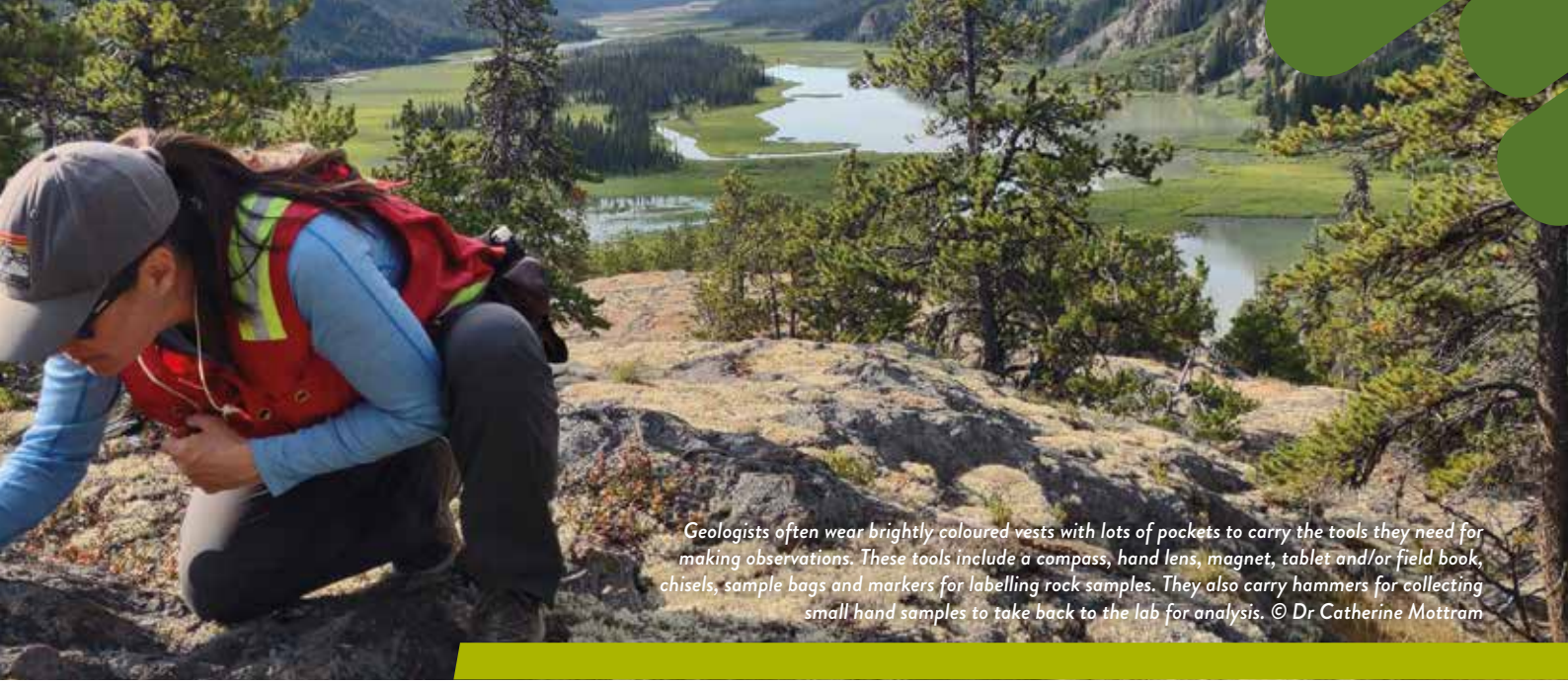
Tectonic plates — large pieces of Earth's lithosphere (the rigid outer layer). Their slow movements create powerful forces that are responsible for phenomena like earthquakes, volcanoes, and the formation of mountains

Exploring the Earth's geological history reveals stories of collision, upheaval and transformation. If we were able to travel millions of years back in time, we would witness continents crashing into each other and mountains rising from the depths of the Earth. These dramatic events have left their mark on the landscape in the form of ancient faults – breaks in the Earth's crust which serve as reminders of the planet's dynamic past. These faults, formed through the intense pressure and movement of tectonic plates, hold within them a wealth of information about the Earth's geological evolution. Dr Dawn Kellett, a research scientist at the Geological Survey of Canada, specialises in the study of dating faults by applying innovative methods to accurately determine how old they are.

Why study ancient faults?

"Present day, active faults are the result of the slow, powerful movement of Earth's tectonic plates. As they slide past one another, the crust breaks, causing earthquakes and landslides," says Dawn. "Ancient faults that were active millions to billions of years ago are important to study because they remain broken and weak. In these fractured zones, fluids and magma (molten rock) deep in the Earth can travel more easily than through solid rock, especially when the faults continue to move even small amounts." These fracture zones facilitate the concentration and movement of essential resources like copper and other metals, which have many industrial and technological applications, including clean energy technology.

Understanding the history of ancient faults sheds light on past configurations of Earth's tectonic plates and reveals important information about potential risks for sensitive infrastructure like dams, bridges, and storage facilities for nuclear energy byproducts. Despite being largely inactive



Geologists often wear brightly coloured vests with lots of pockets to carry the tools they need for making observations. These tools include a compass, hand lens, magnet, tablet and/or field book, chisels, sample bags and markers for labelling rock samples. They also carry hammers for collecting small hand samples to take back to the lab for analysis. © Dr Catherine Mottram

for millions to billions of years, these ancient faults remain weak and may still experience minor movements today, which makes investigating them important for assessing potential risks.

Why is Dawn's research focused on the northern Canadian Cordillera?

The Yukon Territory holds a special place in geological research due to its location within the spectacular northern segment of the Cordillera – a long, narrow mountain belt stretching along the western side of North America. "The mountain belt in this region formed from the collision of a patchwork of smaller parts of continents and chains of oceanic islands with the western margin of the large, old continent of North America," says Dawn. "These all squashed together along fault systems over millions of years to form the mountains we see today, having been scraped off ocean plates to the west that have since sunk beneath North America." This landscape offers important information about Earth's complex history, but dating its faults can be difficult.

The challenge of dating faults

"Dating rocks is an exciting field of geoscience called geochronology, in which we use the miniscule amounts of naturally radioactive isotopes of common elements, like potassium or uranium, trapped within minerals as timekeepers," explains Dawn. "The nuclei of these isotopes decay or change at very slow and well-measured rates, forming stable atoms of another element." For example, as the radioactive isotope of potassium decays, it transforms into a stable isotope of argon gas. By measuring the amounts of both the original radioactive potassium and the resulting stable argon trapped within a mineral, scientists can figure out when that mineral first formed. This method allows researchers to determine the age of the mineral, which could be millions or billions of years old. Unlike rocks, faults do not typically form new minerals, which makes it tricky to use the conventional methods to work out when the faults moved. Nonetheless, new approaches are emerging, allowing researchers like Dawn to explore new ways for dating faults and gaining deeper insights into Earth's geological past.

> **"The big game changers in my field of research are technological advances in lasers and mass spectrometry."**

Technological advances

"The big game changers in my field of research are technological advances in lasers and mass spectrometry," explains Dawn. "We use lasers to zap tiny amounts of material from very small crystals in our rock samples." These state-of-the-art lasers enable Dawn to extract incredibly small amounts of material from rock crystals, with spot sizes as narrow as a few microns. These microsamples are then analysed using mass spectrometry – a technique used to measure the abundances of different isotopes, including radioactive isotopes and the stable isotopes produced by their decay. Comparing the abundance of those particular isotopes provides crucial clues about the age and composition of minerals. With each passing year, improvements in mass spectrometer technology enable scientists to measure even tinier amounts of isotopes, improving the precision of dating methods.

What has Dawn discovered so far?

"We have discovered that faults tend to have very long reactivation histories, and that many of those past slip events were accompanied by the movement of fluids and the precipitation of new minerals, like illite, a datable clay mineral, along the fault surfaces," explains Dawn. This means that while a fault may have formed and experienced most of its displacement over a relatively short period of a few million years, it could then undergo occasional reactivation with minor slips over much longer periods, spanning tens to even hundreds of millions of years. These findings are very exciting as they reveal the complex behaviour of faults and their long-term geological impact.

Dawn and her team are eager to expand their research to other sites. "Detailed fault dating studies have only been performed on a few fault systems in Canada and worldwide," says Dawn. "We are excited to see what new insights we will learn as we expand this work to more fault zones and geological districts in Canada and beyond!"

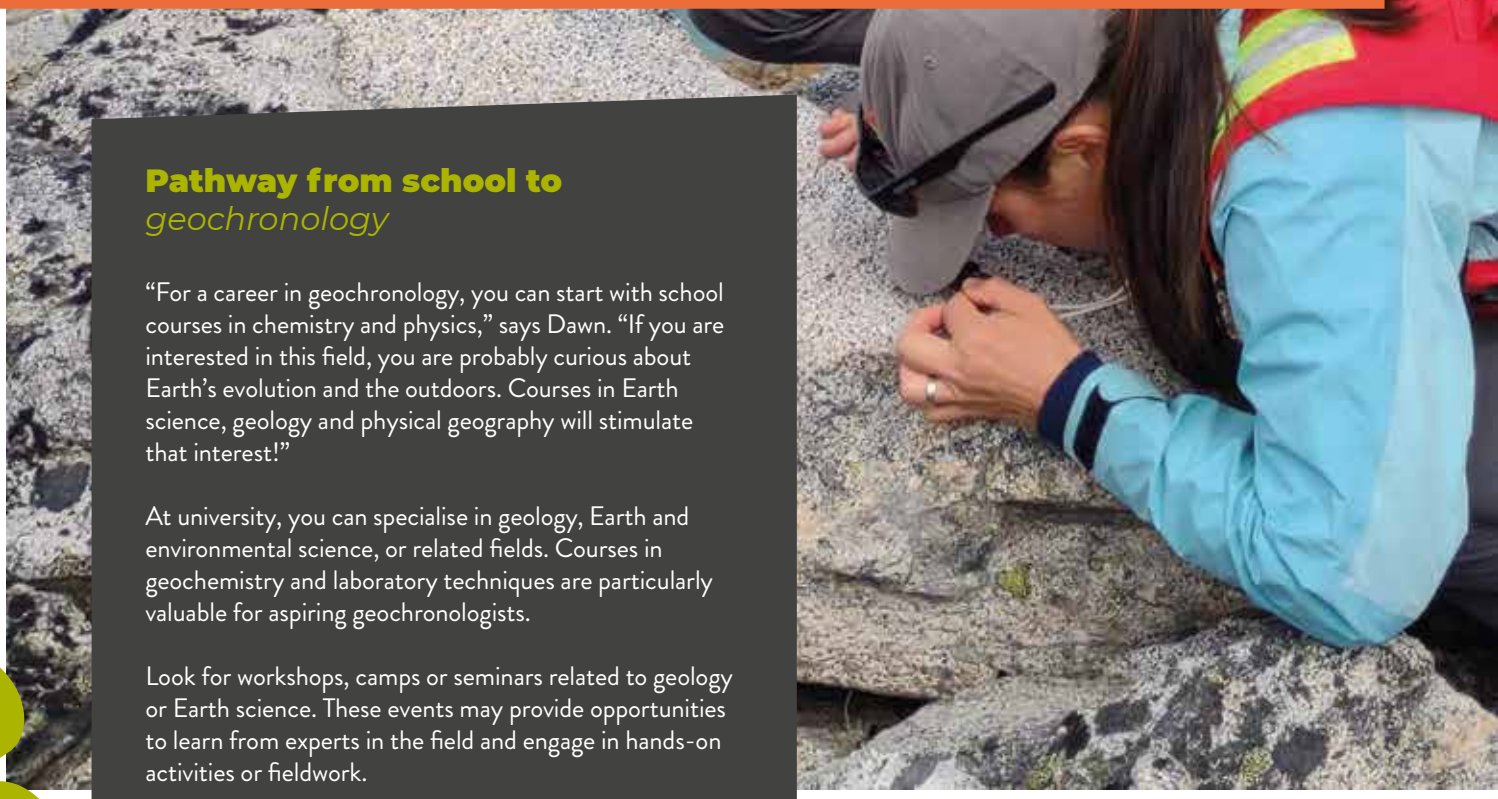
About *geochronology*

Geochronology is a field of Earth science focused on dating rocks, minerals and geological events to understand Earth's history. Using techniques like mass spectrometry, radiometric dating and stratigraphy (looking at rock layers), geochronologists piece together the timeline of Earth's evolution, from its formation to present-day. Their work contributes to various scientific efforts, including understanding past climates, locating mineral resources, and assessing environmental changes and hazards.

Geochronology is a rewarding field which offers a fascinating journey through Earth's history and provides insights into its past, present and future. "It is tremendously exciting to contribute to piecing together Earth's four billion years of history," says Dawn. "There have been a few moments when I have calculated new ages from our samples and realised I am the first person to know something new about Earth's past! That moment of discovery is a really special feeling."

Technological advancements are allowing researchers like Dawn to conduct more accurate research. "I am very excited about the recent introduction of tandem mass spectrometers to geochronology," says Dawn. "These instruments can take material separated from a sample by laser, pass it through a mass spectrometer (mass separation), pass it through a reactive gas (chemical separation) and then through another mass spectrometer." This innovative method lets us researchers study samples that produce 'isobaric interference' – a phenomenon where two different isotopes have the same weight, making it impossible to measure them. For instance, the decay of rubidium to strontium involves the exchange of a proton and a neutron, but no change in mass. Traditional mass spectrometers struggle to isolate these isotopes, making tandem mass spectrometry a revolutionary tool for understanding the mysteries of geological time.

Geochronology holds promise for the next generation of scientists, offering opportunities to not only explore Earth's history but also tackle pressing societal challenges. "There is tremendous opportunity for applying the field of geochronology to important societal issues," says Dawn. "For example, it can be used to better understand how and where critical minerals (materials that are needed for green technologies and the digital future) accumulate in Earth's crust, or to make good choices about geologically stable sites to store CO_2 or nuclear byproducts. By equipping future geochronologists with the necessary tools and knowledge, we can empower them to make significant contributions to scientific discovery and address global challenges in the years to come."



Pathway from school to *geochronology*

"For a career in geochronology, you can start with school courses in chemistry and physics," says Dawn. "If you are interested in this field, you are probably curious about Earth's evolution and the outdoors. Courses in Earth science, geology and physical geography will stimulate that interest!"

At university, you can specialise in geology, Earth and environmental science, or related fields. Courses in geochemistry and laboratory techniques are particularly valuable for aspiring geochronologists.

Look for workshops, camps or seminars related to geology or Earth science. These events may provide opportunities to learn from experts in the field and engage in hands-on activities or fieldwork.

Q&A

Meet *Dawn*

Who or what inspired you to become a geologist?

By the time I finished high school, I knew that I wanted to study the natural world in some way. I began an undergraduate degree in oceanography. However, what really inspired me to become a geologist was an optional course that captured my attention, my love of the outdoors and wild spaces, and my deep interest in history. Once I completed my first field school, I was hooked.

What experiences have shaped your career?

Not all geological research involves field work, but many of us geologists were drawn to the discipline through a love of the outdoors and thrive on observing the natural world. I found that the study of geology gave me the opportunity to move through and study wild spaces that I would otherwise never have had the chance to see, from the Himalayas to the highest mountains in Canada, to the Arctic tundra, to desert landscapes. These experiences have taught me about leadership, resilience, safety and planning, and teamwork. I have also had formative experiences in labs, where I learnt problem solving, patience and creativity, and felt the rewards of automating a process or developing a new way to collect information. For me, field work and lab work go hand in hand. To be able to observe a rock in the field, take it back to the lab to analyse, and then calculate its age in millions of years is truly extraordinary!

You were chair of the Canadian Tectonics Group for several years. What did you gain from this role?

Many of us scientists take on voluntary roles to run scientific societies and groups. It is these communities that take on the role of mentoring young scientists and students, and make sure that they have ample opportunities to gain experience, meet the research community, find peers with similar interests, and connect with resources like scholarships and grants. The Canadian Tectonics Group is a small but mighty community that does all of these things. Our crown achievement is our fall (autumn) workshop, in which students and experts gather together somewhere in Canada for two to three days to look at fascinating rock outcrops outside, share what we know and scratch our heads about what we don't know, get to know our peers, and tell each other about our latest research findings. I was honoured to chair this group for several years. It gave me the chance to meet a whole generation of talented young people in our field of research.

What are your proudest career achievements so far?

My proudest career achievements have been hearing from others that they found my research useful and were able to build on it for their own work.

What are your aims for the future?

In the future, I aim to improve the way that our data are stored, shared and used by contributing to the development of well-curated databases. I am also aiming to learn more about incorporating artificial intelligence in my research and how to read and write software code. Younger generations have a huge advantage in being, on average, much more computer-literate than us older generations, so I'll be looking to learn from and with you!

Dawn's *top tips*

1. Keep up your sciences, even those hard courses.
2. Follow your instincts.
3. It is never too late to learn something once you recognise the need or desire to learn it.

Explore careers in *geochronology*

"Talk to your counsellor about which post-graduate schools in your area are offering specialisations in geology/Earth Science," says Dawn. "When you find one, read the webpages of the professors/instructors as they may be able to help you choose courses, and there may also be opportunities to shadow or volunteer in their lab."

Geochronology is a rapidly evolving field, so it is crucial to stay informed about the latest research findings and methodologies. Websites like Earth Sciences Canada (**earthsciencescanada.com/careers/what-is-earth-science.php**) offer a variety of learning resources and information about career opportunities in geology.

Natural Resources Canada (**natural-resources.canada.ca/simply-science/inspiring-minds-17-ways-get-excited-about-stem/23335**) offers public outreach schemes aimed at inspiring young minds and promoting interest in Earth sciences.

Other websites like Mining Matters (**miningmatters.ca**) and Simply Science (**natural-resources.canada.ca/simply-science**) provide educational resources and information about careers in geology and related fields. Engaging with these platforms can help you explore your interests and learn more about the diverse opportunities available in Earth Science, including in geochronology.

Photo left: *PhD student Sarah Bowie (University of Portsmouth) and Dr Dawn Kellett (Geological Survey of Canada) look through hand lenses to identify the minerals in this rock. Behind them, the Canadian Cordillera of northwest British Columbia, Canada. © Dr Catherine Mottram*

Can statistics help to uncover the ocean's secrets?

There are still many mysteries about the ocean. While this vast store of water is known to support life and help mitigate the impacts of climate change, scientists are constantly making new discoveries about how the ocean functions. At **Dalhousie University** in Nova Scotia, Canada, **Professor Joanna Mills Flemming** and her team are developing new statistical methods to study ocean data, uncovering insights into fish populations and how the ocean's inhabitants will respond to climate change.

Professor Joanna Mills Flemming

Department of Mathematics and Statistics, Statistical Ecology at Dalhousie Laboratory (SEaDAL), Dalhousie University, Canada

PROFILE

Fields of research
Statistics, marine ecology

Research project
Developing new statistical methods for ocean data analysis

Funders
Natural Sciences and Engineering Research Council of Canada (NSERC), Mitacs, Canada First Research Excellence Fund, Canadian Statistical Sciences Insitute (CANSSI)

Talk like a ...

statistical ecologist

Acoustic sensor — a device that uses sound waves to detect the presence of objects

Algal bloom — a rapid increase in the population of algae

Carbon sink — a natural environment which absorbs carbon dioxide from the atmosphere

Mark-recapture — a technique to estimate animal populations when it is impractical to count every individual

Ocean data — observations of or from the ocean, including ocean temperature, currents and chemistry, and marine animal population counts and movement tracks

Population dynamics — how a population size changes in time and space

The Earth is often called the 'Blue Planet', because the ocean occupies over two thirds of its surface area. The ocean is home to a huge diversity of plant and animal life and plays a crucial role in mitigating the effects of climate change. "The ocean (which is one body of water, divided into the Pacific, Atlantic, Indian and Arctic Oceans) stores an estimated 90% of the excess heat caused by climate change and about 25% of human-caused carbon dioxide emissions, making it an incredible carbon sink," says Professor Joanna Mills Flemming, a statistician at Dalhousie University in Nova Scotia, Canada. However, scientists are discovering that the ocean's ability to act as a carbon sink is changing, and further research is required to find out why, and how this change may be affecting the ocean's inhabitants.

Studying the seas with statistics

Joanna works with a team of statisticians, fisheries scientists, oceanographers and marine ecologists in the Statistical Ecology at Dalhousie Laboratory (SEaDAL), where researchers use statistical methods with ocean data to gain deeper insights into how marine ecosystems work. SEaDAL brings together university researchers from various disciplines, including oceanography, biology and statistics,

A grey seal outfitted with tracking equipment and a camera
© Damian Lidgard, courtesy of the Ocean Tracking Network

with those working in government, industry and conservation organisations to address a wide range of ocean-related questions, from the population dynamics of marine life to coastal flood risk.

The challenges of data collection

"There are a range of interesting ocean-related problems that remain unsolved, due in part to our general inability to observe the ocean directly," explains Joanna. This inability is not surprising, considering the average depth of the ocean is around 3.5 km and, at almost 11 km below the ocean's surface, the deepest part of the ocean (the Mariana Trench) is about 2 km further from sea level than the summit of Mount Everest!

Marine scientists use modern technologies to gather data about the ocean and the animals that live within it. For example, satellite images taken from space can provide information about water surface temperatures and algal blooms, while acoustic sensors in the ocean can detect shoals of fish and delineate the shape of the ocean floor. Tags attached to marine animals can enable scientists to track their movement.

Catching fish

In ecological research, a common method for studying populations of marine animals, such as fish, is the mark-recapture technique. This involves catching a large group of fish in a specific area, tagging each captured individual, then releasing them back into the ocean. Later, when scientists return to the same area to catch a similar number of fish, it is reasonable to assume that some of them may already be tagged because they were also part of the first catch. By comparing the total number of recaptured fish to the total number captured, the total number of fish in the area can be estimated.

> **"There are a range of interesting ocean-related problems that remain unsolved."**

Researchers in SEaDAL are investigating whether an alternative method, the close-kin mark-recapture approach, can provide a more accurate and efficient way to estimate fish populations. This involves collecting a sample of fish and analysing their DNA to determine whether any of the fish have kin relationships (i.e., are parents and offspring). These genetic tags can be used within the close-kin mark-recapture framework to estimate the size of the fish population as well as other demographic parameters. "We have learnt a lot about using close-kin mark-recapture," says Joanna. "Not only can it provide reliable estimates of population size, but it can also tell us much about the genetic health of the population."

Incorporating local knowledge

Joanna and the SEaDAL team also collaborate with people who live and/or work by the sea, such as fishers and Indigenous communities, to gather information about the ocean from their lived experiences. "We attempt to build statistical models that fully integrate these data," she explains. Joanna develops models which enable her to separate measurement uncertainty from the uncertainty in our understanding of the processes that are causing changes in the ocean. These models reveal key insights into the systems she studies, such as the population dynamics of different fish species.

"Our research is important as it helps us to understand ocean processes," says Joanna. The SEaDAL team is increasing scientific understanding of the ocean's plants and animals, as well as the ocean itself. "By building statistical tools to model these processes, we are able to better understand how these might be affected by climate change." This knowledge can help future scientists and researchers manage ocean environments and adequately prepare for the impacts of climate change.

About *statistical ecology*

Having a solid knowledge of mathematics and statistics is hugely important for solving ecological problems and helping marine conservation efforts. "Statistics allows us to connect theory with data, enabling us to challenge our ideas, refine them and develop new ones," explains Joanna. "For example, new and/or improved understanding of how marine animals are interacting with their environments can help us to effectively manage and protect critical marine resources."

The joys of statistics

"Being a statistician is exciting and rewarding," says Joanna. Statisticians can work on a huge range of interesting problems and their research can add value to any discipline. Joanna chose to work in marine ecology, but there are many other areas where statisticians have much to contribute, from related fields such as land-based ecology, to applied sciences such as medicine, and even to business.

Being a statistician focused on marine ecology and fisheries science brings its own rewards. "I like to work on important problems that impact those who live in my community as well as to contribute more broadly to a better world," says Joanna. "I also love working in a team environment and with people who know things that I don't. The challenge is always in ensuring that I know enough about the problem of interest to be useful."

An Ocean Tracking Network glider deployed off the coast of Nova Scotia to gather ocean data © Nicolas Winkler Photography, courtesy of the Ocean Tracking Network

Pathway from school to *statistical ecology*

At school and beyond, study mathematics and take any available statistics and applied mathematics courses to learn statistical skills. Study biology to learn about ecology.

You will be introduced to different aspects of marine science in biology (ecology and population dynamics), chemistry (water chemistry and chemical reactions), oceanography (physical, chemical and biological processes in the ocean), physics (physical reactions) and geography (marine ecosystems and landscapes).

You can approach a career in statistical ecology from different directions, depending on your interests and the area you want to focus on. University degree options include statistics, applied mathematics, data science, ecology, environmental science, marine biology and oceanography.

If you decide to study an ecology-related degree, take as many statistics classes as possible. "The quantitative skills possessed by statisticians are the most in demand and the hardest to acquire, so focus on learning statistics and statistical methods," advises Joanna. "Learn how to collect, store, visualise and model data and how to understand uncertainty."

If you choose to study a statistics-related degree, take classes in ecology and oceanography to learn about how to apply your statistical knowledge in these fields.

Explore careers in *statistical ecology*

Learn more about the range of marine statistical ecology research conducted by the SEaDAL team: **www.stat-ecol-dal.com**

CANSSI supports scientists as they develop statistical methods and models to uncover insights from data: **www.canssi.ca**

The Statistical Society of Canada has resources for students and educators: **www.ssc.ca/en/education**

The Ecological Society of America has a Statistical Ecology section: **www.esa.org/stats**

The Royal Statistical Society has information about how to become an environmental statistician: **www.rss.org.uk/jobs-careers/career-development/types-of-job/environmental-statistician**

Meet *Joanna*

When I was younger, I loved soccer, fashion and probability! I was intrigued by the ability to calculate the probability of something occurring (e.g., a soccer team winning a game) and to use this knowledge to assess risks and rewards.

At school, I loved math because the answer is either right or wrong, whereas English is far more subjective and the answer is often open to debate. I had a great Grade 10 math teacher, Mr Russell Boyle, who inspired me to become a statistician.

My undergraduate degree was a combined honours in mathematics, statistics and computer science. I then completed a Master's degree in engineering mathematics, followed by a PhD in statistics. Living by the ocean and working at Dalhousie University, a world leader in ocean-related research, motivated me to focus my statistical work on ocean data.

I am very proud of my graduate students. I care deeply about them and seeing them achieve their dreams inspires me every day.

There has been a lot of discussion about the lack of women in STEM research and how our representation decreases with career advancement. My advice to girls interested in pursuing a career in STEM is to go for it – the sky is the limit! Work hard and have some fun along the way.

A huge scallop harvested off the coast of Nova Scotia
© Tricia Pearo-Drew

What happens when plastics break down into microplastics and nanoplastics?

Microplastics and their even smaller cousins, nanoplastics, are a growing concern for environmental and human health. At the **FAMU-FSU College of Engineering** in Florida, USA, and the **University of Alberta** in Canada, environmental engineers **Dr Jeffrey Farner** and **Dr Olubukola Alimi** are studying what happens as plastics degrade into microplastics and nanoplastics, and how this pollution interacts with other substances.

Dr Jeffrey Farner

Department of Civil and Environmental Engineering, Florida A&M University – Florida State University (FAMU-FSU) College of Engineering, USA

Department of Civil and Environmental Engineering, University of Alberta, Canada

Dr Olubukola Alimi

Department of Civil and Environmental Engineering, University of Alberta, Canada

PROFILES

Fields of research
Environmental engineering, environmental chemistry

Research project
Studying the release, transport and fate of microplastics and nanoplastics

Funders
Natural Sciences and Engineering Research Council of Canada (NSERC), Environment and Climate Change Canada, Alberta Conservation Association

Talk like an ... **environmental engineer**

Adsorb — to stick to the surface

Brownian motion — the continual random motion of particles in a fluid due to the constant movement of atoms

Colloid — a suspension of particles that are too small to settle out on their own

Microplastic — a small piece of plastic debris (<5 mm)

Nanoplastic — an even smaller piece of plastic debris (<0.001 mm)

Plastic polymer — a molecular chain formed of repeating units of carbon and hydrogen

Weathering — the physical and chemical transformation and breakdown of a substance

Plastic pollution is a pressing global issue. Less than 10% of plastic ever produced has been recycled, and many million tonnes of plastic waste have entered the environment. While images of turtles choking on plastic bags send a powerful message about the dangers of plastic pollution, some of the consequences are much less visible, but just as concerning.

When plastic breaks down into tiny pieces, it begins interacting with the environment in new and troubling ways. At the FAMU-FSU College of Engineering and the University of Alberta, Dr Jeffrey Farner and Dr Olubukola (Bukola) Alimi are investigating the changes that occur as plastic degrades. Worryingly, scientists have discovered that plastic pollution now exists in every part of the planet, found in sea creatures living in the deepest and remotest depths of the ocean and in drinking water around the world.

How are microplastics and nanoplastics formed?

Like any material, plastics degrade over time. Sunlight, heat, and the action of water, sand and microorganisms all physically and chemically break plastics down. “If you’ve ever picked up an old plastic

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bag and had it fall apart, you've seen how weathering impacts plastic," says Jeff. "As plastic is weathered, the surface undergoes chemical changes, it becomes brittle and small particles break off." These particles are known as microplastics (when <5 mm) and nanoplastics (when <0.001 mm).

What are the effects of microplastics and nanoplastics?

"In general, bulk plastic is a safe material – it's one of the reasons why we use it for so many applications," explains Bukola. "However, when plastic particles approach the nanoscale, they can move across biological barriers." This means if you ingest nanoplastics by drinking water or eating meat containing them, the tiny plastic particles can pass through your intestinal walls and enter your bloodstream. "We're seeing this happen in animals, including humans, but we don't yet know the health implications," says Bukola.

Jeff and Bukola are concerned about the impacts of low concentrations of microplastics and nanoplastics in the environment over long periods of time. As this pollution is now everywhere, any negative impacts could have severe consequences for ecosystems. "For instance, nanoplastics might impact reproductive success over multiple generations," says Jeff. "Or exposure to nanoplastics might make organisms more susceptible to other toxic substances."

Why does size matter?

As you break something into smaller pieces, you increase its total surface area. For example, a plastic cube of 1×1×1 cm has a volume of 1 cm^3 and surface area of 6 cm^2. If you cut this cube into a thousand cubic millimetres, the total volume will stay the same, but the total surface area will increase to 60 cm^2. By the time the piece of plastic has weathered into trillions of nanoplastic particles, its surface area will be over a million times greater. This means there is significantly more plastic surface for reactions to take place on and more sites for other substances, such as toxins, to adsorb to.

The tiny size and large surface area of nanoplastics means they have some unusual physical and chemical properties. In water, nanoplastics form a colloid – a suspension of particles that are small enough to remain in suspension indefinitely. "Milk is a great example of a colloid," says Bukola. "It is a suspension of fat and protein molecules in water." Once nanoplastics enter water, they do not settle out on their own and so they can travel great distances from their source.

How do Jeff and Bukola study something so small?

"Nanoparticles are too small to see under a regular microscope," explains Jeff. "However, if we shine a laser at a colloidal suspension of nanoplastics, the light will be scattered." This process, known as dynamic light scattering, allows Jeff and Bukola to determine the size of the particles they are studying. Brownian motion causes the particles in the suspension to constantly move, but larger particles will move more slowly while smaller particles will move more quickly. "We look at how the scattered light changes to understand how big our plastic particles are," explains Jeff.

What have Jeff and Bukola discovered?

"Weathering not only decreases the size and increases the surface area of plastics, it also oxidises them," explains Jeff. When oxygen is added to the plastic polymer, it causes chemical and physical changes to the plastic. "This means weathered plastics can behave very differently from the original plastic," says Jeff. "This makes studying plastics interesting, because you need to consider the starting material and the weathering process to understand microplastics and nanoplastics."

As plastics are weathered to microplastics and nanoplastics, the changes in surface properties are of particular concern. "The particles often become more negatively charged, which makes them more stable in water," explains Bukola. "It also causes other compounds to adsorb to the surface of the plastic. While the nanoplastic itself might not be toxic, the substance attached to it might be." For instance, if a nanoplastic adsorbs a toxic metal particle then enters an animal's bloodstream, it will carry the toxic metal with it.

In this way, nanoplastics are not only contaminants themselves, but are also carriers of other contaminants. "The question is, which is the bigger concern?" asks Jeff. "And what does this mean for the environment?" Jeff and Bukola hope that their research will help answer these crucial questions and provide evidence about the risks associated with microplastics and nanoplastics. Plastic pollution has never been a more pressing issue, and understanding its impacts will encourage consumers and policymakers to rethink our unsustainable relationship with plastics.

About *environmental engineering*

Environmental engineering incorporates knowledge and techniques from across science and engineering to address environmental challenges in the world. The breadth of these challenges leads to a diverse field, with environmental engineering careers in areas such as air and water quality management, waste management, pollution control and climate change mitigation.

What challenges are environmental engineers addressing?

"One of the greatest challenges is figuring out how we can maintain a healthy environment, despite our constant need to use it," says Jeff. "For instance, we're always going to need water – for drinking, agriculture and industry. How do we use this precious resource wisely?" Addressing the challenge of water scarcity and quality involves finding new ways to reuse wastewater, keep water clean and use it more efficiently.

"The next generation of environmental engineers will be tasked with addressing a myriad of challenges," says Bukola. "Emerging contaminants (which include pharmaceuticals, pesticides and nanomaterials) are of particular concern, because they release into our lands, air and water and have the potential to harm ecosystems and humans." Solving the issue of contaminants requires innovative and collaborative environmental engineers who will develop technologies and industrial processes that result in a cleaner and more sustainable environment.

"There is increasing pressure on our natural resources," says Bukola. "We need people who are passionate about addressing these challenges. You should be excited about pursuing a career in environmental engineering because it will allow you to protect the environment and improve people's everyday lives."

Pathway from school to *environmental engineering*

At school, studying chemistry and mathematics will give you a strong foundation for pursuing further studies in environmental engineering. Biology and physics would also be useful.

At university, a degree in environmental engineering, another engineering field, chemistry or environmental science could lead to a career in environmental engineering.

Jeff and Bukola recommend taking chemistry and statistics courses alongside engineering courses in topics such as thermodynamics and fluid mechanics. "These will equip you with knowledge of chemical reactions and tools to design systems to solve environmental problems," says Bukola.

"It is wonderful that environmental engineering covers such an enormous range of topics, because anyone can find their passion somewhere under that giant umbrella," says Jeff. This means you can customise your courses to align with your interests, whether that is in water resource engineering, solid waste management, environmental policy, air or water quality, or site remediation.

Explore careers in *environmental engineering*

"There are so many careers available in environmental engineering," says Jeff. "From water and wastewater engineers, to analytical chemists testing water quality, to microbiologists looking for new ways to clean contaminated sites – the list goes on and on."

Other roles include policymakers, environmental consultants, data analysts and science communicators. "We need more people who are skilled at communicating research with the public," says Jeff. "It is crucial for society to understand what we are doing and why, and to appreciate and embrace new technologies."

The Challenger Learning Center is the outreach facility of the FAMU-FSU College of Engineering. It runs a wide range of activities for high school students, including a broad range of summer camps covering areas from engineering through to science communication: **www.challengertlh.com**

The University of Alberta's Women in Scholarship, Engineering, Science and Technology programme offers summer research programmes for students and allows them to unleash their curiosity by participating in hands-on STEM activities: **www.ualberta.ca/women-in-scholarship-engineering-science-technology/index.html**

Meet *Jeff*

As a teenager, my interests were music, soccer and reading. I still enjoy them today – music provides the soundtrack to my days, and I play soccer while travelling. These days, I read more scientific articles than books, but I still firmly believe that reading is an amazing way to explore the world.

As an undergraduate student, my favourite courses were analytical chemistry and environmental chemistry. I liked understanding how instruments worked and how chemistry could be applied to the outdoor world.

My first job was as an analytical chemist for the State of Iowa. I tested drinking water for the presence of pesticides. It felt good to ensure that people's water was safe, but I didn't like the fact that my part in the process ended once I had reported the presence of pesticides. I wanted to protect and restore water supplies rather than just point out the problems. This motivated me to go to graduate school to study environmental engineering.

A key challenge in engineering is to not only work out what's possible, but what's feasible. If you have a solution to a problem but it's very expensive, or you can't convince people that it's safe, then it's not going to happen. Research is often focused on figuring out what's possible and it's easy to forget the feasibility side. But it's necessary if you want to see your solutions in the real world.

I firmly believe that 'outside is the best side'. If I can be outside, I know I'll have a nice time, regardless of weather. This can be cycling, hiking or cross-country skiing in the winter. Just being surrounded by nature with my family and friends recharges my battery.

Jeff's *top tips*

1. Find the thing that interests you. If you're curious to learn more, dive in! Many people giving career advice will tell you, "I didn't have a real plan, I was just interested and kept going."

2. Don't be afraid to try new things. Maybe you get an opportunity to study abroad or to work somewhere that you don't feel qualified for – if you're interested and excited, take that chance.

Meet *Bukola*

When I was younger, I was passionate about basketball – it was a great stress reliever and brought a lot of fulfilment. My family also gave me a deep love of reading. It was our family tradition that my dad always bought newspapers, even if it meant spending his last kobo (Nigerian currency). We all took it in turns to read the newspapers, which exposed me to a wide range of topics and gave me an awareness of events in the world around me.

Growing up in the oil-rich Delta State of Nigeria, I was confronted with many environmental issues, from gas flaring to oil spillage to mismanaged waste. I had a strong yearning to see positive changes, which inspired my passion for environmental engineering.

I originally trained as a chemical engineer but have consistently found myself drawn to the environmental side of the field. My journey towards environmental work began during an undergraduate internship at a water treatment facility with Chevron Nigeria. Since then, I have made deliberate efforts to explore practical solutions to environmental pollution, especially concerning water quality.

The most rewarding part of my work is knowing that I contribute to the global efforts aimed at solving some of the environmental problems we face today. It's refreshing to identify a problem or knowledge gap that affects many people in their everyday lives and work towards addressing it.

Maintaining a good work-life balance is my priority. I enjoy going to the gym, doing long hikes on Saturday mornings, and watching documentaries. I've also recently started practising meditation, which helps my mental health and overall well-being.

Bukola's *top tips*

1. Find your motivation and hold on to the reason(s) why you want to achieve something. My journey hasn't been easy, but it has been rewarding, and motivation helped me focus on the big picture whenever I felt lost.

2. Seek out mentors who have travelled the road you hope to take. Talk to them, hear their stories, ask questions and be inspired.

Can microalgae improve honeybee health?

Thanks to their work as pollinators, bees play an essential role in agriculture. However, modern agricultural practices and climate change mean many bees are becoming malnourished. In the **US Department of Agriculture's Honey Bee Breeding, Genetics, and Physiology Research Laboratory**, **Dr Vincent Ricigliano** is improving bee health by developing pollen substitutes and edible vaccines using microalgae.

Dr Vincent Ricigliano

Honey Bee Breeding, Genetics, and Physiology Research Laboratory, US Department of Agriculture Agricultural Research Service, Baton Rouge, Louisiana, USA

PROFILE

Field of research
Molecular biology

Research project
Developing microalgae as a sustainable and nutritious food for bees

Funders
US Department of Agriculture – National Institute of Food and Agriculture – Agriculture and Food Research Initiative (USDA-NIFA-AFRI), Project *Apis m.*

Talk like a ...

molecular biologist

Amino acids — molecules which form proteins, the 'building blocks of life'

Colony — a family of bees

Crop — a commercially grown plant, usually for food

Gene editing — a laboratory technique to add, remove or alter DNA in a gene

Malnutrition — not having enough nutrients

Microalgae — single-celled photosynthetic organisms

Monocrop — a single crop grown across a large area

Nectar — the sugary fluid produced by plants to entice insects to pollinate them

Nutrient — a substance essential for life that must be consumed by an organism

Pathogen — an organism that causes disease, such as a virus

Pollen — the male spores produced by a flower

Pollen substitute — an artificial food given to bees that mimics the nutritional value of pollen

Pollination — the transfer of male pollen to the female part of a flower (the stigma), resulting in fertilisation

Strain — a genetic variant

"One third of our food supply depends on pollinators such as bees," explains Dr Vincent Ricigliano, a molecular biologist in the US Department of Agriculture's Honey Bee Breeding, Genetics, and Physiology Research Laboratory. As such, bees are essential for food production.

Why are bees essential for agriculture?

Bees feed on plant nectar (for energy) and pollen (for nutrients). In the process, they transfer pollen between flowers. This fertilises the plant, forming seeds that allow new plants to grow. While wild bees have been pollinating plants for millions of years, modern agricultural practices rely on commercially managed colonies of honeybees (*Apis mellifera*) to pollinate crops.

Billions of bees are transported around the US every year, following

the flowering schedule of different crops. In February, honeybees are taken to California to pollinate almond trees, before being driven to the Pacific Northwest in March to pollinate cherries and apples. At the beginning of April, they are transported across the country to Maine for the blueberry season, before heading to Florida at the end of April to pollinate oranges and lemons. In May, the colonies are taken to the Dakotas, where the bees spend the rest of the year producing honey from clover fields.

Over the course of this 7000+ mile journey, commercially managed honeybee colonies pollinate billions of dollars' worth of crops, fertilising the plants and resulting in the fruits and nuts that we eat. Therefore, commercial beekeeping plays a vital role in food supply systems. However, bees are under threat.

Why are bees suffering from malnutrition?

"Thanks to modern agricultural practices and climate change, both managed and wild bees are suffering from malnutrition," says Vincent. Bees thrive on diverse diets containing nectar and pollen from a variety of plants. However, monocrop farming means that bees (both wild and commercial) can only feed on a single species at a time, and climate change is altering when flowers bloom and how much nectar and pollen they produce.

A lack of pollen diversity in a bee's diet means it lacks the nutrients it requires, leading to malnutrition. And malnourished colonies cannot grow healthily or fight off diseases. As a result, beekeepers must feed 'pollen substitutes' to their bees. These mimic the nutritional value of pollen, supplementing the low-quality diet that commercially managed bees eat. Vincent and his team are aiming to make these pollen substitutes more nutritious and sustainable.

How can microalgae act as pollen substitutes?

Vincent is developing pollen substitutes from microalgae (single-celled photosynthetic organisms). "In addition to being a protein source, containing all the amino acids that are essential for bees, microalgae are also a good source of fats that are important for bee health and colony growth," he says.

Vincent works with beekeepers to test the effectiveness of his microalgae pollen substitutes. They feed the microalgae to bees that are used for commercial pollination of monocrops and monitor the health of the colonies. This includes measuring how colony size changes over time, how many young a colony produces and winter survival rates. "We've found that microalgae are a promising feed additive that can provide essential amino acids and fats to honeybees," says Vincent. "We have also observed that these microalgae diets stimulate the bees' immune systems, helping them to fight off diseases."

How can microalgae act as edible vaccines?

To enhance the health benefits of his microalgae pollen substitutes, Vincent uses gene editing techniques to create entirely new strains of microalgae. These engineered strains target the bees' immune systems to respond to specific pathogens. He describes these engineered microalgae as 'edible vaccines', as when bees eat them, not only do they receive all the nutrients they need, but they are also protected against specific diseases.

To test his edible vaccines, Vincent feeds the engineered microalgae pollen substitutes to bees in the laboratory, then deliberately infects them with the viruses the vaccines are designed to prevent. He then measures the bees' health to check whether the vaccine in the microalgae is effectively stopping the virus. "We've discovered that engineered strains of microalgae can help target specific bee pathogens, such as the notorious deformed wing virus, which is linked to the deaths of millions of honeybee colonies worldwide," says Vincent.

What are the benefits of using microalgae?

Microalgae grow quickly and easily, meaning they could be used to mass-produce pollen substitutes and edible vaccines for bees. "Microalgae production is highly sustainable, removes carbon dioxide from the atmosphere, and does not require pesticides or antibiotics," says Vincent, highlighting the environmental benefits of creating pollen substitutes and edible vaccines from microalgae. "Overall, our research indicates that microalgae have the potential to sustainably improve bee nutrition and health using resources that do not compete with human food production." Thanks to Vincent's work, we can be optimistic about the future of our important honeybee populations.

About *molecular biology*

Molecular biology is the study of the molecular workings of life. It focuses on molecules such as DNA (which contains genetic information), RNA (which carries messages and instructions to cells) and amino acids (which build proteins), as well as how these interact with cells. Molecular biology is a wide-ranging field. While Vincent genetically modifies microalgae and examines which amino acid and fat molecules they produce, other molecular biologists might apply biochemistry techniques to improve human medicines or use bioinformatics to understand more about how plants and animals function.

What are the joys and challenges of molecular biology?

Vincent enjoys the combination of field work and laboratory work in his research. "Studying bee molecular biology gives me the best of beekeeping and laboratory experiments." Most molecular biologists conduct experiments in laboratories before analysing their results on computers. This work is precise and requires attention to detail. "I spend lots of time moving small volumes of clear liquid between test tubes," says Vincent. "Working at the molecular scale means you can't physically observe what you're working on, so you need an imaginative mind to help you visualise what is happening at each step."

Molecular biology research has wide-ranging impacts for medicine and agriculture. "This field helps us understand diseases, how medicines work, and the potential for advanced techniques such as gene editing," explains Vincent. Molecular biologists are needed now more than ever to understand and solve real-world problems affecting the living things on our planet.

Pathway from school to *molecular biology*

Study biology, chemistry and mathematics at school and beyond to build a strong foundation. These subjects will probably be entry requirements for a degree in biological sciences.

At university, a degree in biology, molecular biology, cell biology, biochemistry, genetics or biotechnology could lead to a career in molecular biology.

"Look for internships or volunteer opportunities with local farms, research labs or universities to gain hands-on experience," advises Vincent. "Help out however you can and ask to be taught basic laboratory techniques and how to apply them."

"Get involved in agriculture-related extracurriculars activities or projects, like a school garden or a science fair, to apply what you learn in a real-world context," recommends Vincent.

Explore careers in *molecular biology*

Molecular biologists are in high demand to help understand and solve the problems facing the natural world and human populations. You could find yourself protecting food supply chains, preventing diseases or mitigating the impacts of climate change.

Molecular biologists usually conduct research for universities, governments or private industries.

The American Society of Biochemistry and Molecular Biology has a range of educational and careers resources: **www.asbmb.org/education**

The US Department of Agriculture offers student internships: **www.usda.gov/youth/career**

Keep up to date with molecular biology news and cutting-edge research: **www.theconversation.com/global/topics/molecular-biology-1391**

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Q&A

Meet *Vincent*

What inspired you to become a molecular biologist?

I was an imaginative kid; I always liked to make and grow things. This interest in how things work led to a fascination with how the small details of life work. In turn, this led me to molecular biology – the study of life at a tiny scale.

Why have you focused your work on bee health?

I am motivated by a desire to contribute positively to agriculture and food production. Nutrition has an important role in bee health, and pathogens are a main factor involved in bee colony losses. It feels right to focus on these major issues. It is exciting to think about my work positively impacting agriculture by improving honeybee health!

> ***Just like a person adapting to a new environment, the colony works together to handle changes, such as finding new food sources.***

What is your favourite fact about bees?

A honeybee colony is considered to be a superorganism – a group of organisms that work together as a community. Each bee in the colony has a special job. For example, the queen bee is responsible for reproduction (laying eggs) and pheromone production (releasing chemicals that control the colony and keep everything in order). This is similar to how your body contains parts that have their own functions but work together. Just like a person adapting to a new environment, the colony works together to handle changes, such as finding new food sources. This teamwork makes the whole colony act like one big living creature, where every bee is important.

Exposing environmental injustice through maps and stories

Often, it is society's poorest and most vulnerable people that are most exposed to environmental harm. This injustice is the subject of much research, but getting the evidence needed to bring about major change can be challenging. **Dr Stephanie Rutherford**, at **Trent University**, and **Dr Michael Classens**, at the **University of Toronto**, have teamed up with two local organisations in the Canadian city of Nogojiwanong/Peterborough to document the relationship between social vulnerability and environmental risk in the area, with the aim of driving policy change.

Dr Stephanie Rutherford

Associate Professor, School of the Environment, Trent University, Canada

Funders
Social Science and Humanities Research Council of Canada (SSHRC), Symons Trust Fund for Canadian Studies

Dr Michael Classens

Assistant Professor – Teaching Stream, Faculty of Arts and Science, School of the Environment, University of Toronto, Canada

Funder
Social Sciences and Humanities Research Council of Canada (SSHRC)

Fields of research
Communities and cities, food and agriculture, social and environmental justice, social sustainability

Research project
Mapping for Change: Environmental Inequality and Resilience in Nogojiwanong/Peterborough – mapping the landscape of environmental justice and how people and communities are organising to address it

PROFILES

Talk like an ...

environmental justice researcher

BIPOC — Black, Indigenous, and people of colour

Demographic — statistics related to communities or populations, such as age, race or income

Environmental harm — damage to the environment (that typically also damages people)

Environmental risk — the likelihood or vulnerability of an environment (and people) suffering harm

Racialisation — the process by which people and groups of people are defined by their race in ways that privilege or disadvantage them

In Canada, the long shadow of colonialism is felt in persisting environmental injustices. These injustices are not always immediately obvious but can have a serious impact on health and well-being over multiple generations. Dr Stephanie Rutherford and Dr Michael Classens are exploring environmental injustices in the town of Peterborough, in Ontario, Canada, by collecting and analysing a range of data that demonstrates these inequalities. Peterborough is also known as Nogojiwanong, which means 'place at the end of the rapids' in Anishinaabemowin, the Indigenous language of the territory.

Peterborough has a strong activist history, helping to connect the dots between research and action, so Stephanie and Michael are not working alone. "We have teamed up with two partner organisations which focus on justice, equity, inclusion and environmental access," explains Stephanie. These organisations are the Community Race Relations Committee of Peterborough (CRRC) and the Kawartha World Issues Centre (KWIC). "These community partners are directly involved in the design, direction and implementation of the research goals," says Michael.

What is environmental injustice?

"There are decades' worth of research, especially in the US, that shows a relationship between social

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inequality and environmental risk or harm," says Stephanie. "Research in Canada has shown that this is particularly the case for Indigenous communities." This relationship can manifest in a wide variety of ways. For instance, vulnerable communities are more likely to live near sources of pollution, such as factories or mines, and have fewer resources, such as access to healthcare, to combat the effects of environmental harm.

"Humanities professor and author Rob Nixon calls this 'slow violence'," says Michael. "Long exposure to environmental harms and lack of access to decision-makers due to marginalisation often leads to accruing effects on health." For instance, exposure to toxins or pollutants can lead to cancers and respiratory and reproductive diseases, and the effects of climate change, such as flooding and extreme weather events, will disproportionately affect those with fewer resources available to respond. "There are also indirect impacts," says Stephanie. "A lack of access to green space can affect mental health, water and soil contamination can make communities dependent on others for food and clean water, and a lack of trees in neighbourhoods can increase vulnerability to extreme heat events."

Data for change

Unsurprisingly, such environmental risks lead communities to believe that decision-makers do not care about their health and well-being. Getting the authorities to address the situation is often not easy, as communities face the burden of providing evidence to prompt change. For marginalised communities already struggling to meet daily needs, such efforts are out of reach. Stephanie and Michael are hoping that they can address this issue by combining their scientific training with the drive and knowledge of local organisations.

"Peterborough is a small city with a big industrial legacy," says Michael. "We are interested in exploring the impacts of that legacy on local people." The team is using quantitative methods, which include mapping exercises, and qualitative methods, such as interviews and photography, to explore these impacts on different demographics – and, most crucially, how interventions can help bring about environmental justice.

Impactful maps

Maps can be powerful tools for visually displaying persuasive datasets. For instance, if a map shows that areas of industrial pollution overlap significantly with the residencies of marginalised communities, this is compelling evidence of environmental injustice. "Being able to demonstrate the disproportionate burden shouldered by some groups provides the kind of proof that decision-makers are looking for in terms of policy development," explains Stephanie. "Maps make it difficult to ignore these relationships."

To collect such spatial data, the team first turned to government data sources about environmental issues such as contaminated sites, polluting facilities, landfills and climate vulnerability. "We mapped these data against demographic data covering variables such as race, income, education, and people with disabilities," explains Michael. "This helped us build an index of vulnerability to see who experiences the most environmental risk in Peterborough."

The team found that government data was insufficient for its needs – some of it was not at a fine enough scale, and some data did not exist at all. "For example, there were no data on waterborne illnesses on First Nations reserves – a huge issue because many communities do not have access to clean drinking water," says Stephanie. Stephanie and Michael are now assessing how they can collate their own datasets, to use in their own project and to share with local social and environmental organisations.

The power of stories

Quantitative data are powerful, but they never tell the whole picture. While hard data are useful for policy makers, understanding what such data mean at the personal level – for the people impacted by environmental injustice – is vital. "Through interviews and oral histories, we are supplementing the map with stories of people's lived experience of environmental risk and harm," explains Michael. "We also have a project that invites community members to take pictures of the environmental goods and bads that they experience every day, which makes for striking visual evidence."

The aim is for this combination of quantitative and qualitative data to tell a fuller picture of the situation to policy makers, strengthening the case for change. The data will also be publicly available. "We are making a freely accessible living digital archive of data, maps, images and stories," says Stephanie. "A core principle of this project is that the data should be available to anyone who wants to use them."

Evidence of injustice

The Mapping for Change project has already unveiled some serious instances of environmental injustice in Peterborough. "In our mapping work, we are finding that poverty is a key indicator of exposure to potentially harmful contaminants," says Stephanie. "People living on former industrial sites tend to have lower incomes and a higher proportion of lone parent households." Through interviews with former industrial workers, the team has documented occurrences of occupational diseases – illnesses such as cancers that have arisen due to exposure to toxins during their work. "In our photography work, we are also exploring how people experience environmental justice," says Michael. "We are developing themes such as the privatisation of space, impacts of industry, and the lack of accountability from those responsible for causing environmental harm."

The team is now readying to release their map to the public. "We anticipate that it might generate a lot of questions, both from community members and local politicians," says Stephanie. "We plan to write policy briefs that highlight key results for the government, as well as communicate our results to the public through infographics, fact sheets and newspaper articles."

The project has also built its own community. "Through sharing photos and talking openly about personal experiences, the participatory element of our research is building solidarity among the group," says Michael. "We are lucky to be able to learn from individuals and community organisations acting for change."

The pathway to change

The team hopes that municipal and government authorities will take notice of the results and acknowledge the environmental injustices happening in Peterborough. "The disproportionate burden of environmental harm violates the Ontario Environmental Bill of Rights and the right to a healthy environment under the Canadian Environmental Protection Act," says Stephanie. "Government needs to acknowledge this and help bring about the change needed." Data that the team has collected not only demonstrate the problems but can also be used to generate solutions. "We would like these data to lead to real and lasting policy change at a variety of levels," says Michael. "Most crucially, we need structural change and better access to decision-making for these vulnerable communities."

Now, Stephanie and Michael are planning to supplement their map with further data, gathered through their own efforts. "We are planning to test for contaminants in the soils of former industrial sites," says Stephanie. "We also have a project which will explore the colonial impacts of the Trent Severn Waterway as a form of environmental injustice." This waterway is a 240-mile-long canal, whose construction disrupted Indigenous practices and led to dispossession of land, but whose long-lasting impacts are not fully understood.

Public access remains at the heart of the team's work. "We are developing a photography exhibition to showcase the amazing images captured by our research participants," says Stephanie. "We are also working with academics and community organisations to host a data symposium on the need to produce and analyse locally-relevant data to promote social and environmental change." By building these connections, future efforts can use these collaborative networks to kick-start further research and interventions for environmental justice.

About *environmental justice*

There are plenty of environmental issues in the world, and these often have a negative effect on people's health and well-being. However, they do not affect all people equally. Environmental justice research aims to examine the inequalities in how people are affected by environmental harm, and what demographic differences lie at their heart. Typically, environmental injustices are closely tied to social injustices – and addressing both simultaneously is critical to building a fairer world.

Understanding environmental injustice involves understanding the experiences and perceptions of those affected. "Environmental justice research gives us the opportunity to work with and learn from community members who have lived experience of environmental risk," explains Stephanie. "In our research, they have taught us so much about the inequalities that shape our community. As university professors, our privilege often insulates us from this."

As environmental issues evolve over time, environmental justice will remain a key area of research. "For instance, the unequal burdens of climate change will continue to be an area in need of a lot of research," says Michael. "As the impacts of climate change worsen, researchers will need to pay close attention to how these impacts are distributed."

Stephanie and Michael emphasise that environmental justice research involves an understanding of both social and environmental perspectives. "A good grasp of both the scientific and social dimensions is key to finding solutions to environmental problems," says Stephanie. "Research in the field typically involves interdisciplinary teams of environmental and social scientists."

Meet *Stephanie*

I am a social scientist. My work explores the intersections between the environment and social inequalities, such as racism, classism, sexism and colonialism. I also work on human-wildlife conflict, thinking about how human changes to the environment impact animal populations, which is also a form of injustice. I have always been a scholar who wants to see justice in the world – both for humans and nonhumans. This inspires all my work.

I grew up in a working-class community in Toronto. There was a lot of industrial activity, combined with a lack of green space. This prompted me to think about how power – and access to power – shapes the kind of environmental risks people experience.

> ***I think it is really important to pay attention to the challenges of where you live...***

My proudest career achievement is the Mapping for Change project. It has the potential to have tangible, real world impacts for the community I live in. I think it is really important to pay attention to the challenges of where you live, and I seek to do research that changes those conditions.

I would like to see the Mapping for Change project expand beyond Peterborough. Other former manufacturing towns in Ontario, including Hamilton, London, Oshawa, Sarnia, Sudbury and Windsor, are all part of a larger story about the environmental impacts associated with industry. This much bigger project would involve academics and community partners in each of these communities.

Stephanie's *top tip*

Keep asking questions about why things are how they are. Young people are so important for holding older generations to account on issues like climate change. Use your education to back up your demands for change with actionable data.

2023 Youth Leadership in Sustainability at KWIC Poster Marking Party. © Sarah Forrest

Meet *Michael*

In high school, I did a project on industrial chicken farming, and it was a revelation to me. I learnt how socially unjust, environmentally destructive and ethically fraught industrialised agriculture is. My career has been shaped by working with communities and people engaged in struggles for social and environmental justice.

I work with so many incredible people. I'm very grateful to have the opportunity to work with so many fantastic organisations, students, staff and colleagues at the University of Toronto, and beyond. I hope to continue to have the opportunity to work with dedicated and passionate people who are engaged in work to realise a more just and sustainable world.

Michael's *top tip*

The two feminist economists (who share the pen name) J. K. Gibson-Graham talk about 'here and now' as the best starting place for the fight for change. In other words, start where you are with what you have, and go from there. And always make room for hope and joy!

Community *partners*

Stephanie and Michael partnered with two community organisations for their Mapping for Change research. This access to community connections and expertise allowed them to focus their research on people with lived experience of environmental injustice – people who are often absent from academic research. Understanding the perspectives of these people is vital to addressing environmental injustice.

Community Race Relations Committee of Peterborough (CRRC)

Patricia Wilson

Coordinator, Community Race Relations Committee of Peterborough, Canada

Fields of research

Anti-racism, institutional and systemic discrimination, public education, human rights, diversity, environmental justice

Funders

Ontario Trillium Foundation, City of Peterborough, Trent University

CRRC is a community-based non-profit organisation, committed to promoting positive race relations in Peterborough, Ontario. Its activities include community-based advocacy, collaborations, and education. Patricia Wilson, CRRC's Community Advocate & Outreach Coordinator, explains more.

"Stephanie and Michael approached CRRC in 2021, asking us if we were interested in collaborating on the Mapping for Change project. We signed on as a lead partner because the project's work fits squarely in our mandate.

"CRRC is a central member of the project's advisory committee. We weigh in on decisions and help to shape the project's direction. We are also responsible for anti-oppression training for all research team members.

"Seeing the map of environmental risk and social vulnerability take shape has been great. It will be a tangible visualisation of the ways in which race, class and environmental risk intersect.

"We want to see real change come from this research; the results should work for the community. We think that the map, the photovoice images, and the oral histories will help tell the story of environmental justice in this community in a way that prompts – or forces – policy-makers to address inequities.

"We lead a range of initiatives and programming that help to address and combat racism in Nogojiwanong/ Peterborough. Last year, we ran a research project that explored the impacts of racism and racialisation on BIPOC community members. It's particularly focused on the impact of COVID-19 on Peterborough's BIPOC communities and the emerging needs that have come from the pandemic aftermath. CRRC will use this research to inform the development of services that better meet the needs of racialised individuals in our community, help inform the strategic direction of the organisation and act as community research that can be used to inform policy and be leveraged by organisations to access more funding and support to better address BIPOC community needs."

Sam Rockbrune, Patricia Wilson and KWIC Chair Ryan Sisson during a KWIC annual general meeting © KWIC

Pathway from school to *environmental justice research*

Stephanie and Michael highlight how important an interdisciplinary approach is. They recommend studying subjects such as biology, chemistry and environmental health, alongside geography, social studies, economics and political science.

Universities offer undergraduate courses in subjects that can explore or relate to environmental justice, such as environmental science, geography, law and social studies.

Kawartha World Issues Centre (KWIC)

Sam Rockbrune

Executive Director, Kawartha World Issues Centre, Canada

Fields of research

Socio-legal studies, gender equality, campus sexual violence, law, intersectionality

KWIC is a charitable organisation that connects global issues to local initiatives. It aims to create opportunities to change perspectives and foster equitable and sustainable communities, through community education, programmes with youth and schools, and umbrella support for small and emerging initiatives. KWIC's Executive Director, Sam Rockbrune, explains more.

"KWIC has a 35-year history in Nogojiwanong/Peterborough. We have developed a strong reputation for being a community connector and for working on global issues such as climate and environmental justice. The Mapping for Change project recognises the importance of community organisations, given we often understand best what is happening on the ground and have strong connections with community members.

"I provide overall leadership to our team. As a partner on the Mapping for Change project, we support the project steering team in its decision making, such as suggesting pathways for research to be shared with youth. I have also facilitated training sessions with the research team, and KWIC has shared calls for participants and updates on the research. When final results are in, we will help ensure they are shared with the community.

"For me, the biggest highlight of the project has been delivering training. I facilitated a workshop on Popular Education and Best Practices and enjoyed spending a few hours with the researchers to hear more about the project's details, and share KWIC's experiences and knowledge for driving impactful conversations.

"I'm hoping this project will be a turning point. I want it to open doors for more work on environmental injustice, especially for racialised communities. One of the project's many objectives is tangible change, so seeing leaders make decisions based on the project's findings would be phenomenal.

"We facilitate many projects to encourage and support young changemakers in our community. In Spring 2024, our Returning to Mother Earth, Gender Equality (SDG5) and Climate Action/Justice (SDG13) workshops will start, and we are hoping to offer mentorship and leadership programmes for young changemakers. 2024 is also our 35th anniversary, so we will celebrate by bringing the community together!"

Sam's career

"I didn't have a plan in mind to get to where I am now. When I graduated high school, all I knew was that I wanted my career to make a difference and pay my bills! At 17 years old, I decided law was the way to go, and while I'm not in that field now, both my degrees and the experiences they entailed led me to my current role.

"Finding a community of like-minded individuals has been pivotal. Having peers who want to make a difference and who also encouraged me to step into leadership roles, has been fundamental to where I am now. As a racialised woman, I am beyond grateful for the many other BIPOC women and non-binary folks who built this community with me.

"Now as a leader and changemaker, I really appreciate the lessons every organisation and experience taught me, especially the community members who practise care, kindness, joy, and giving yourself a break when you need to as central to social justice work."

Sam's *top tip*

Find your community. Social and climate justice work can be difficult and lonely at times. You're working against big, global, interconnected problems, and, sometimes, having someone send you a silly meme or backing you up in a meeting can make all the difference and encourage you to continue.

Explore careers in *environmental justice*

Trent University, where Stephanie works, hosts an Enrichment Program (**www.trentu.ca/conferences/home/youth-programs**) for high school students, which includes courses on environmental issues. The university also hosts the annual Peterborough Regional Science Fair (**www.peterboroughsciencefair.com**), which provides an engaging and practical entry into science and technology.

The University of Toronto, where Michael works, hosts Youth Climate Action Toronto (**youthclimatetoronto.ca**), which supports young people in developing strategies for youth engagement in climate action.

ECO Canada has a broad range of resources for those looking to work in the environmental field in Canada. This includes training and education support: **eco.ca/environmental-professionals/employment-funding-and-job-board**.

According to Glassdoor, the average salary for an environmental researcher in Canada is around CAN $55,500 per year.

How are archaeologists uncovering the secrets of an Ancestral Maya boomtown?

Famous for their large stone pyramids, and with advanced skills in construction, agriculture and mathematics, the Ancestral Mayas were once a powerful civilisation that lived across much of modern-day Mexico and Central America. **Dr Meaghan Peuramaki-Brown**, an archaeologist at **Athabasca University** in Canada, leads the Stann Creek Regional Archaeology Project to investigate the ancient town of Alabama in Belize. Along with **Matthew Longstaffe**, from the **University of Calgary**, and a team of local Mayas, they are shedding light on how and why Alabama developed and what life was like for the people who lived there.

Dr Meaghan Peuramaki-Brown

Associate Professor, Athabasca University, Canada

Matthew Longstaffe

PhD candidate, University of Calgary, Canada

PROFILES

Field of research
Archaeology

Research project
The Stann Creek Regional Archaeology Project (SCRAP) – Excavating an Ancestral Maya town in Belize

Funder
Social Sciences and Humanities Research Council of Canada (SSHRC)

Talk like an ... archaeologist

Ancestral Mayas — a civilisation that occupied modern-day Mexico and Central America from approximately 2000 BCE to 1600 CE

Artefact — an object made or used by humans (e.g., pottery, stone tools) uncovered during an excavation

Boomtown — a settlement characterised by sudden and rapid population growth and development

Excavation — a technique used in archaeology to uncover a site by slowly and carefully removing soil and sediment to expose ancient structures and artefacts

Geochemistry — chemical analysis of geological material, such as soil and sediment

Mayas — Indigenous Peoples of Mexico and Central America who are descended from the Ancestral Mayas

Wattle-and-daub — a construction technique in which woven sticks (wattle) are filled with soil (daub)

An intriguing mystery lies hidden in plain sight within an orange grove in Belize. Between neat rows of orange trees, mounds of earth and stone rise up – the remains of an Ancestral Maya town that hold clues to uncovering the secrets of an ancient civilisation.

"To a trained eye, it is clear to see how the town was laid out, as the different types of mounds represent different buildings in what was once a thriving 'downtown' core surrounded by residential areas," explains Dr Meaghan Peuramaki-Brown, who leads the Stann Creek Regional Archaeology Project (SCRAP). The original name of this abandoned town has been lost, but it is known today as Alabama, named after an American banana company that operated in the area in the 1950s.

The Stann Creek Regional Archaeology Project

As a collaboration between archaeologists and residents of the nearby village of Maya Mopan, SCRAP aims to excavate Alabama to learn more about the people who once lived there. Input from local Mayas is essential to the project, as they are culturally descended from the Ancestral Mayas. "We consult with community members throughout all stages of the research process, from designing research questions to

The 2019 SCRAP field team during excavations at Alabama © SCRAP

conducting excavations to communicating results," explains Meaghan. "Maya input is critical as it is their history that we are uncovering and exploring."

What was Alabama like?

From 700 CE to 900 CE, Alabama was a bustling town, consisting of a well-defined urban core that included temples, a ballcourt and administrative structures. "Most of the approximately 1,000 residents lived in surrounding settlement zones in small wattle-and-daub houses thatched with palm leaves," says PhD candidate Matthew Longstaffe. "These houses were built on top of raised rectangular platforms made from granite and earth." Larger family groups occupied multiple platforms, forming small residential compounds. While the houses themselves no longer exist, the platform structures still lie among the orange groves of Maya Mopan.

Was Alabama a boomtown?

Meaghan and Matthew believe that Alabama was an example of an Ancestral Maya boomtown. "Boomtowns are settlements that experience sudden and rapid population growth, accompanied by rapid development of infrastructure and economic growth," explains Matthew. "This is often caused by changes in political or economic conditions that create opportunities for development." SCRAP's excavations have revealed that Alabama's urban core and surrounding settlement zones experienced rapid development from 700 CE onwards. As the population suddenly increased, new structures were built in a diverse range of architectural styles.

"We have several hypotheses to explain Alabama's boom, as there were probably many contributing factors," says Matthew. It is likely that Ancestral Mayas realised this was a desirable place to settle when they discovered the many natural resources that could be exploited from the surrounding area (including granite, clay, salt and cacao). Regional sociopolitical events and changes in trade routes may also have caused population movements.

How do archaeologists study ancient sites?

"Analysing the structures and artefacts (and their contexts) uncovered during excavations is crucial to archaeological research," explains Meaghan. Recently, the SCRAP team has been uncovering and examining the architectural features on platforms to gain an insight into the original appearances and functions of the buildings that once sat on top of them. "Temples, houses and storerooms will all look different and contain different artefacts," explains Matthew.

Pottery artefacts are key to uncovering the lives of the Ancestral Mayas. Near temple platforms, the team has found ceremonial artefacts, such as incense burners. In contrast, everyday pottery objects such as tools for preparing and cooking food have been found associated with house platforms. And the presence of large serving vessels may indicate that some families hosted communal feasts. The team analyses the composition of pottery artefacts to determine whether they were made with local clay or imported to Alabama from elsewhere in the region or beyond. "This information helps us reconstruct trade networks and understand how they evolved with time," explains Matthew.

Organic materials, like the wattle and palm thatch used to build houses, are rarely preserved in the tropical environments of Belize. So, in addition to studying the structures and artefacts that have survived the test of time, the team also analyses the geochemistry of soil and sediment samples. Variations in different elements can indicate where the Ancestral Mayas discarded organic materials or planted gardens and fields. "Combining architectural and artefact analysis with soil and sediment geochemistry allows us to build a more complete picture of daily life in Alabama," says Matthew.

What have Meaghan and Matthew discovered about Alabama?

SCRAP's excavations and analyses have uncovered evidence that the Ancestral Mayas of Alabama were able to adapt to the regional landscape and took advantage of locally available resources. Pottery was crafted from local clay, tools were made from local stone and platforms were built from local granite and earth. "Alabama architectural choices are unique in the Ancestral Maya world (where most construction was with limestone) which reflects their adaptation to the local environment," says Matthew.

The team has uncovered strong evidence that Alabama was an innovative boomtown, and there are clues (in the form of imported pottery and stone tools) that point to extensive trade networks with other communities in the region and beyond. "This suggests that Alabama was a hub of economic and cultural exchange within the broader Ancestral Maya world," says Matthew. Thanks to the work of the SCRAP team, we are learning more about the lives of these ancient peoples.

Matthew digs among the orange groves of Maya Mopan to uncover the Ancestral Maya town of Alabama © SCRAP

About *archaeology*

"Archaeology is an amazing career!" says Meaghan. "It is a privilege to be part of it." As the study of the human past, archaeologists study the structures and artefacts left behind by previous communities and use these to understand what their lives were like.

A day in the life of an archaeologist

During excavations at Alabama, the SCRAP team are onsite and ready to start work by 7 am. In addition to professional archaeologists and archaeology students, most of the team is from the nearby village of Maya Mopan. The local Mayas work as field assistants, supervisors and community liaisons, and provide the team with delicious food.

Excavations involve carefully removing soil and sediment with trowels and brushes to uncover artefacts (such as fragments of pottery) and structures (such as sections of platforms). "We maintain detailed records of the excavation process," explains Matthew. "Artefacts, written descriptions, photos, maps and sketches all contribute data that we use to interpret the site."

By 3 pm, when it has become too hot to work outdoors, the team returns to their camp (stopping for a cooling drink along the way) to continue their work in the laboratory. All artefacts found that day are documented then carefully cleaned with toothbrushes.

What key skills do archaeologists need?

Communication and collaboration are key skills for archaeologists, as they work in interdisciplinary teams and engage with local communities. "You need to be able to communicate with different audiences, work well in a group and have empathy towards others," says Meaghan. "A good sense of humour also helps!" Archaeologists also need to be adaptable and flexible so that they can adjust their plans when things go wrong ("They will!" says Meaghan). "Archaeologists need perseverance to persist through long hours of fieldwork, often in challenging conditions," says Matthew. "They must also be able to critically evaluate evidence to draw meaningful conclusions."

Pathway from school to *archaeology*

At school and beyond, geography and history will introduce you to some of the foundations of archaeology. "Develop a broad knowledge base in geology (to learn about landscapes, sediments and soils) and anthropology (to learn about human societies and cultures)," advises Matthew.

A university degree in archaeology will equip you with the theoretical knowledge and practical skills necessary for conducting archaeological research. "Alongside this, take courses in geographic information systems (GIS), socio-cultural studies and the language(s) relevant to the area of the world where you want to work," advises Meaghan.

Gain hands-on archaeological experience by joining a dig or volunteering with archaeological or historical societies.

Explore careers in *archaeology*

Archaeology is a broad field. For example, bioarchaeologists study human remains, zooarchaeologists study animal remains, and geophysical archaeologists perform surveys to map structures below the ground surface.

Learn more about the Stann Creek Regional Archaeology Project (SCRAP; **www.scraparchaeology.com**) and watch this video to see what a day in the field involves: **www.youtube.com/watch?v=ACOQkyeZltA**

Visit Sapiens (**www.sapiens.org/archaeology**) and Archaeology (**www.archaeology.org**) to read accessible articles about archaeology research.

Many archaeology organisations have resources for students, including the Canadian Archaeological Association (**www.canadianarchaeology.com/caa/student-resources**), the Society for American Archaeology (**www.saa.org/education-outreach**) and the Society for Historical Archaeology (**www.sha.org/students-and-teachers**).

Meet *Meaghan*

When I was younger, I loved being outdoors and participating in sports (basketball, volleyball, running, swimming, folk dancing, etc.). I also loved reading, doing puzzles and hanging out with friends and getting into trouble!

As a child, I loved flipping through my Grandma's National Geographic magazines, looking at images of archaeological sites and finds. My mom loved learning about the Ancestral Mayas and meeting present-day Mayas, and her enthusiasm rubbed off on me. We had several family holidays to Mexico which probably influenced my decision to study the cultures of the region.

> ***I always get excited by architectural finds that give us a glimpse into the mind of the builder.***

As an archaeologist, I most enjoy all the opportunities I have to work with different people. I love working with colleagues and community members around the world. The best thing about archaeology is that it's a team sport. I don't consider myself a 'people person', so this can be challenging for me, but it's very rewarding to invest time and energy into building relationships with others and to share the experience of telling human stories.

Recently, I directed the excavation of an interesting staircase at Alabama. We found a large lump of clay wedged below one step – we don't know why, but I think someone might have been trying to level the step (like when you put something under the leg of a wobbly table). I always get excited by architectural finds that give us a glimpse into the mind of the builder.

One of my favourite memories from working at Alabama doesn't have anything to do with the archaeology itself. At lunch, we were sitting in the shade and one of the women in our team, who was from Maya Mopan, told us folktales from her village. It was wonderful to learn about the connections that the Mayas who currently live in the area have with the landscape and surrounding world.

Meet *Matthew*

Music was my main interest when I was at school – I played the guitar and was obsessed with practising and playing in bands. My interest in archaeology came from reading and watching National Geographic. This opened my eyes to so many incredible places I wanted to explore and people I wanted to meet.

Archaeologists get to go places and do things that many people will never experience, from camping in the jungle to exploring and excavating ancient towns. Doing physically demanding work in bad weather while spending a long time away from home is not for everyone. But for me, these challenges make the experience all the more enriching.

In my opinion, it's the people I work with who make archaeology worthwhile. Archaeologists get to meet, work with, and form relationships and friendships with all sorts of interesting and unique people. Some of my closest lifelong friends are people I've met through archaeological fieldwork.

Alabama is an amazing place to work because it's in a region that is not well understood. It's very fulfilling to examine all the information we've collected over the years, which is telling us so much about how people at the site lived their day-to-day lives, how they were connected to other parts of the Maya world, and the relationships that they formed and maintained.

I have many amazing memories from archaeology fieldwork in Belize, Mexico and Canada. The first season of my dissertation fieldwork began with a month of work in Mexico followed by two months in Belize at Alabama. It was gruelling, but it reminded me why I love archaeology. I got to camp in the jungles of southern Mexico, travel by myself across the Yucatan Peninsula to Belize and spend two months excavating at Alabama. These experiences give me the inspiration to continue with archaeology research.

Meaghan and Matthew's *top tips*

Get out of the classroom and gain practical experience in archaeology to discover whether you like fieldwork. Find local archaeology digs or societies – you don't need to travel to exotic locations to gain experience.

There are many careers in archaeology, so be flexible about which cultures, techniques and research topics you explore.

How much should political parties know about you?

With so much of our lives shared online these days, it is often easy to get hold of someone's personal data. Political parties can use this information to target voters with specific messages tailored to each person's interests. At the **University of Victoria** in Canada, **Professor Colin Bennett, Dr Smith Oduro-Marfo** and **Jesse Gordon** investigated how political parties around the world use their citizens' data and what this means for democracy.

Professor Colin Bennett

Department of Political Science, University of Victoria, Canada

PROFILE

Field of research
Political science

Research project
Understanding how political parties access and use voters' personal data, and what this means for privacy and democracy

Funder
Social Sciences and Humanities Research Council of Canada (SSHRC)

Talk like a ...

political scientist

Data protection — laws designed to protect the right to privacy and regulate how organisations collect and use personal information

Democracy — a system of government in which the population elects their leaders and enjoys basic rights and freedoms to participate in public affairs

Echo chamber — an environment in which you are only exposed to views that match your own

Electorate — all the people entitled to vote in a population

Micro-targeting — a form of advertising in which the advert is specifically targeted to the individual's interests and background, based on personal data that has been harvested about them

Polarisation — division into opposing groups based on specific opinions or beliefs

Swing voter — a voter who has not yet decided which party to vote for

Wedge issue — a very divisive issue, used to draw voters away from an opposing party

In the run-up to elections, social media is awash with political advertising. In the past, political parties campaigned using messages that could target a wide audience. Today, thanks to the incredible wealth of personal data that is available about each of us, campaigners know far more about a voter's likes and dislikes so can target their political messages directly to individual voters and groups.

These micro-targeting practices raise issues of privacy and data protection and lead to questions about the health of our democracies. To campaign effectively, just how much should political parties know about their voters? Professor Colin Bennett, a political scientist at the University of Victoria, worked with his former students, Dr Smith Oduro-Marfo and Jesse Gordon, to investigate how different countries use personal data for political campaigning, and what this means for democracy.

How do political parties collect voters' personal data?

"Political parties could have a wide range of personal data on individual voters," says Colin. In addition to names and addresses from electoral registers, they might have information about people's political views from petitions they have signed online or comments they have made on social media. "These practices are not just observed in Western democracies," says Smith. "In many African countries, the proliferation of the internet and mobile phones has created an opportunity for political parties to harvest personal information."

In some countries, political parties buy personal data from data brokers,

who harvest information (e.g., online shopping habits, social media activities and even health conditions) from the internet and use it to construct profiles of individuals. Many people are unaware of quite how much of their data they are permitting others to access. "If a US citizen has subscribed to anything without reading the privacy policy, it is possible their data has been sold to a political party," says Jesse. "In the US, political parties have few privacy restrictions and lots of campaign financing, so they can collect a lot of profiling information from data brokers." In contrast, while data brokers do exist in other democracies, privacy laws limit what personal information they can sell without an individual's consent.

How do political parties use voters' personal data?

Once a political party knows what a voter likes and dislikes, they can personalise their campaign messages to align with that person's views. "Micro-targeting can happen when a party has enough information on a person or group to tailor messaging to their specific interests," explains Jesse.

While this approach can help voters learn about parties' stances on issues close to their heart, it also raises significant concerns. "Some argue that micro-targeting encourages parties to deliver messages on 'wedge issues' that drive polarisation," explains Colin. "It can also produce 'echo chambers', where individuals only see information algorithmically calculated to match their presumed interests." This can lead to narrow perspectives on a party's mandate and can limit exposure to different viewpoints. "Micro-targeting can lead to political parties focusing on smaller groups of swing voters rather than the broad electorate," says Jesse. "At its most extreme, it's possible for a party to make entirely opposite campaign promises to different groups."

While micro-targeting is not yet a common technique in many Global South countries, Smith notes that the harvesting of phone numbers from digital and non-digital sources in many African countries is used to send bulk texts to thousands of voters. "Although this 'mass-targeting' technique allows small political parties to reduce their campaign costs, the absence or emergent nature of data protection laws in many of these countries may not adequately protect against personal privacy breaches," he says. There is also a risk that bulk messages sent by faceless entities can spread false information, which can undermine trust in politicians and negatively impact the quality of democratic participation.

Why is there tension between data privacy and political campaigning?

Finding the balance between data protection and providing parties with information on voters' concerns is tricky. "Political parties have the right to know about voters' beliefs and the duty to communicate with the electorate," says Colin. "But how much voter information do they actually need?" While some argue that the more information the better, others say this opens the door for manipulation. "Democracy relies on political parties that understand their voters," explains Jesse. "However, there is a certain point where people may feel uncomfortable with how their personal information is collected and used."

How do these tensions play out in different countries?

The team analysed relationships between data protection laws and political campaigning in different countries and discovered a wide variation in how privacy laws apply to political parties. In the US, weak privacy regulations encourage a huge voter analytics industry, while in Japan, harvesting personal data and many forms of political campaigning (including micro-targeting and door-to-door canvassing) are prohibited. Political parties in the EU are regulated by strict data protection laws that limit how they can gather and use people's information.

Many countries in the Global South are beginning to adopt digital technologies, such as fingerprints, to verify voters' identities when they vote. "This is supposed to prevent fraud, but most Western democracies don't collect such invasive data from their voters," says Smith, who is concerned about gathering sensitive personal data in countries without strong data protection laws. "I hope there will be a matching commitment to developing data protection regulations," he continues. "If not, such data could be abused, which could dissuade citizens from registering to vote and therefore undermine democracy."

It is clear that as the digital world advances, data protection and privacy must be a priority for ensuring that elections remain fair and democratic.

About *political science*

Political science involves using scientific techniques to study political trends and their effects on society. "In recent years, there has been a widespread debate about foreign influence on elections and the spread of misinformation," says Colin. "It's now easy for anyone to anonymously set up social media accounts and spread false information." While some countries have regulations to suppress misinformation, it is a difficult battle when social media companies typically focus on driving engagement. "This has been exploited by foreign actors to erode democratic stability," says Jesse. "It has allowed conspiracies to gain mainstream footings and impacts how people engage with politics."

Despite efforts to quell this trend, it is expected to remain a key issue for the next generation of political scientists. "Young people need to be critically aware of the erosion of democratic values," says Colin. "They need to know how companies collect and process their personal data, and how to address it."

The advent of artificial intelligence (AI) has also been disrupting political systems. "We live in a time of growing misinformation, resource scarcity, inequality and climate change," says Jesse. "Each of these issues may be improved or made dramatically worse by AI systems." For instance, AI raises the stakes for misinformation, as it becomes easier for malicious actors to generate authentic-looking deepfake videos of politicians saying or doing things that never actually happened.

Smith notes that there are many opportunities emerging in the Global South as countries adopt new technologies and surveillance techniques. "We should always be asking: is this change improving welfare and well-being?" he says. "Is it making governments more efficient and accountable?" The end goal of political science should be to understand which political systems work best for the people they serve, so understanding these changing trends is essential.

Pathway from school to *political science*

At school and beyond, study humanities and social science subjects, such as history and social studies.

At university, degree options include politics, political science, international relations, sociology, or philosophy, politics and economics.

"Politics touches every subject," says Colin, so consider how your interests could intersect with a career in political science. "Be driven by what you are curious about and interested in," says Smith. "There is no one way to become a political scientist."

"Be interested in what is happening in your city, your country and the world," advises Jesse. "Read the news and challenge your bias. If you see something that agrees with your world view, try to learn more about it from different perspectives."

Explore careers in *political science*

As a political scientist, you could investigate how different political systems function or apply your skills to support political campaigns.

Consider joining the youth wing of a political party, a youth parliament (e.g., British Columbia Youth Parliament: **www.bcyp.org**) or a Model United Nations club (**www.un.org/en/mun**), which will expose you to the application of politics in real or simulated environments.

For more information, the International Association of Political Science Students (**www.iapss.org**) provides events and resources for students and the Journal of Surveillance and Society (**ojs.library.queensu.ca/index.php/surveillance-and-society**) publishes academic articles on the theme of data privacy and surveillance.

Meet *Smith*

Senior Program Officer, British Columbia Public Service

I grew up in Ghana with a strong interest in politics. This began as an interest in general knowledge because I loved trivia quizzes. I always wanted to learn new facts, which exposed me to the history and politics behind these facts. From a young age, I was interested in news stories from the radio, TV and newspapers. The more stories I heard, the more my interest was piqued.

I joined my school's debating club and took part in debating competitions against other schools. I also wrote and published articles about our school leadership, and I acted as the campaign strategist for my friends who stood in elections for school prefect positions. From these interests, it felt natural to pursue political science at university.

Privacy and surveillance in Africa are understudied. There are arguments that development challenges in Africa are partly due to the inability of governments to monitor their citizens, meaning, for example, governments may not adequately 'know' their citizen's needs or how much to tax them. This has led to a proliferation of surveillance tools, which can be very dangerous in an environment where data protection regulations are still developing. During my PhD research, I advocated for the need for balance between government empowerment and the rights of citizens.

I now work for the Ministry of Children and Family Affairs at the British Columbia Public Service. My role involves developing and implementing policy, which ties in to my interests in politics. I am often assigned to tasks involving privacy, such as conducting privacy impact assessments and dealing with consent forms, which help me to stay in touch with the field I am passionate about.

Smith's *top tips*

1. Read the news and stay up to date with current affairs.

2. Treat everyone's opinions with respect. If you disagree with someone's position, ask questions to try and see the situation from their point of view. Being a kind and tolerant human being will make you a better political scientist.

Meet *Jesse*

Policy Analyst, Legislative Assembly of British Columbia

As a kid, I watched lots of World War II movies with my dad. I wanted to know more about why the war happened, and as I started digging, I became interested in the political dynamics and socio-economic conditions that caused the conflict. By the time I was a teenager, my interest had expanded to current national and global politics.

Growing up, I never really knew what I wanted to do for a career. I left high school thinking I wanted to be an actor, but then went to university thinking I'd become a psychologist. After a year, I left university to spend time working and travelling. Exploring other places, meeting new people and seeing how different societies organised themselves was an illuminating experience. I decided to return to university, where I took a range of classes on topics I found interesting, which eventually led me to political science.

My current job as a policy analyst benefits from my skills in conducting research, critical thinking, problem solving and conveying information. In my previous role, I used my research skills to support parliamentary committees reviewing privacy legislation.

People don't sufficiently consider the potential impacts of digital systems on society. We give up our personal data freely – our phones are constantly tracking where we are, what we watch, what we buy, etc. We believe we can trust the companies that collect this data, but most of us don't understand what is being done with this information. Many people don't think about the power of their data until something bad happens, like a privacy breach or identity theft.

Jesse's *top tips*

1. Be curious and ask questions. If you don't know the answer to something, do some research. This will help you gain knowledge and ask better questions.

2. It doesn't matter if you don't know what you want to do with your life yet! You will keep changing and growing, so just find something that interests you and try to do some good in the world.

Improving police performance by training officers to manage stress

Policing is a high-stress occupation in which making mistakes can have serious consequences. **Dr Judith Andersen**, a Canadian researcher specialising in psychophysiology and health, has teamed up with **Dr Harri Gustafsberg**, a Finnish retired police officer who now works as a mental resilience coach, and **Dr Joseph Arpaia**, a psychiatrist in the US. Together, they have developed an innovative training method to help police officers understand and manage their psychological and physiological responses to stress, enabling them to make better decisions in the line of duty.

Dr Judith Andersen

Psychophysiology and Health Researcher, Department of Psychology, University of Toronto, Canada

Dr Harri Gustafsberg

Retired Chief Inspector, Police University College of Finland

Mental Resilience Coach, Suomen Mentoritiimi Oy, Finland

Dr Joseph Arpaia

Psychiatrist, Oregon, USA

Research project
Developing a programme to reduce police officer stress and improve decision making

Funders
Canadian Institutes of Health Research (CIHR); Social Sciences and Humanities Research Council (SSHRC); Ontario Ministry of Labour; Connaught Fund; Canadian Foundation for Innovation; Ontario Research Fund

PROFILES

Talk like a ...

psychophysiologist

Autonomic nervous system — the part of the nervous system that regulates involuntary physiological processes

Biofeedback — monitoring a physiological response, such as heart rate, and using this information to control it

Heart rate variability — the variation in time intervals between heartbeats

Parasympathetic nervous system — the part of the autonomic nervous system which relaxes the body after periods of stress and helps to modify overactivation of the sympathetic nervous system

Psychophysiology — the study of how the mind and body interact

Sympathetic nervous system — the part of the autonomic nervous system that helps the body activate the 'fight or flight' response

Vagus nerve — the nerve that, as part of the parasympathetic nervous system, sends signals between the brain, heart, lungs and digestive system

Policing is a prime example of a career in which appropriate responses to dangerous situations are vital. Police officers are trusted to de-escalate threatening situations with minimal use of force. However, even though police training emphasises this approach, the body's stress response can override this training and cause an officer to make mistakes in the heat of the moment. In some cases, this can lead to tragic outcomes. Understanding and controlling this stress response is, therefore, crucial.

To address this challenge, Dr Judith Andersen, from the University of Toronto, assembled a team of experts who each brought unique skills to her project. As a psychophysiology and health researcher, Judith has expertise in the development of field-based psychophysiological interventions. She paired up with Dr Harri Gustafsberg, who understands the stress of policing first hand from his experience as an

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operational commander in the Finnish Police National Special Intervention Unit and from his work as a mental resilience coach. Together, they teamed up with psychiatrist Dr Joseph Arpaia, who is an expert in psychophysiology-based treatments and behavioural modification. "We each bring unique expertise from our fields," says Judith. "Working together means that we are more confident in the positive results of our research and fieldwork."

Responses to stress

The body's response to threats is powerful. A surge of chemicals, including adrenaline and hormones such as cortisol, can trigger the 'fight or flight' response, which primes the body to take rapid physical action to escape or overcome a threat. "When this response is moderate, it enhances performance through more accurate vision, hearing, motor control and reaction time," explains Judith. "However, when the response is more severe, it can negatively affect performance." For instance, people experiencing an extreme stress response may have distorted thinking and poor motor control. Overactivation can impact their decision-making ability when dealing with threats. And recurring extreme stress activation increases the risk of the person developing physical and mental health conditions.

Our autonomic nervous system regulates involuntary physiological processes, such as heart and breathing rates, and is responsible for the physiological changes that we experience during stressful situations. "The parasympathetic nervous system (the part of the autonomic nervous system responsible for recovery and focused attention) is suppressed within milliseconds of a stressful situation arising," explains Joseph. "This allows unchecked activation of the sympathetic nervous system (the part of the autonomic nervous system that readies the body for fight or flight)." This increases heart and breathing rates, but also decreases cognitive processing, oxygen delivery to the brain, and fine motor skills. "This process is beneficial for purely physical tasks, such as running and fighting," says Joseph. "However, other skills, such as verbal abilities and response inhibition, become less effective. Police need the ability to simultaneously engage physical, verbal and social skills to de-escalate situations and improve safety. That was an existing gap in police training that our research addresses."

Hearts and minds: the research process

Judith first visited Harri at the Police University College of Finland in 2013. Over the next year, they observed officers and collected psychophysiological data during high-intensity training exercises. Judith's research lab is an 'ambulatory' lab, meaning it contains equipment that allows her to measure psychophysiological responses to stress in the field, rather than in the lab. This means she can measure police officers' heart and breathing rates and hormone levels while they move around and take part in training scenarios.

"Collecting data during fast-paced critical incident scenarios, such as simulated accidents or active shooter drills, was challenging," says Harri. "Equipment that works in the lab often fails in field settings, so we had to identify techniques that accurately monitored officers on the move." This led Judith and Harri to Joseph. He had developed psychophysiological monitoring equipment and software for treating his patients, which was just what the team needed for monitoring police officers. Over the years, Judith, Harri and Joseph uncovered how and why police officers at every level (from new recruits to those in top-level tactical units) respond to stress during active duty. "We found that increased heart rate is an indicator of activation of the sympathetic nervous system and suppression of the parasympathetic nervous system. This leads to a greater risk of making mistakes, such as forgetting to use de-escalation techniques or using unnecessary force," says Judith. "We also observed that many officers were unable to recover quickly from stressful situations, putting them at risk of exhaustion, burnout and future mistakes." These results indicated a need to develop techniques that allow officers to have greater control over their stress responses.

Listen to your heart: biofeedback training

One variable the team measured in officers was the variation in time between heartbeats, known as heart rate variability. "Healthy heart rate variability indicates an adaptive response to stress, but severe or long-term stress can cause heart rate variability to become unhealthy," says Judith. "We use heart rate variability biofeedback (HRVB) to help officers know when their heart rate variability is reaching unhealthy levels, so they know when to apply techniques to keep it in a healthy range."

HRVB involves monitoring real-time changes in heart rate variability and using this information to control it. Using the heart rate monitor and app designed by Joseph, police officers can observe their heart rate during training exercises and

understand the extent to which their body's stress response affects their physical and psychological state. They can also see how the use of techniques, such as breathing training, can control their heart rate variability and improve their performance.

The team developed training techniques that use HRVB to help officers better regulate their stress response. "The first technique we teach is the 'reset breath'," says Joseph. "This is a prolonged exhalation that gives the brain a short window of time to shift attention from the stress response and refocus on the task at hand." By stimulating the vagus nerve, a key component of the parasympathetic nervous system, the reset breath allows for a more balanced interplay between the sympathetic and parasympathetic nervous systems. The team describes this technique as a 'manual override' of the stress response that, with repeated training, can be conditioned so that officers perform this technique in stressful situations without even thinking about it. This reset breath is integrated into live action fieldwork settings through the team's 'Reset, Refocus, Respond' technique.

The team found that HRVB training was a powerful way to improve police officer performance. "We observed that HRVB training was associated with reduced use of force, fewer lethal force errors, improved communication skills and improved situational awareness," says Harri. "This training not only makes situations safer for the public, but it also improves the health of officers by preventing chronic stress from accumulating over time."

iPREP: International Performance Resilience and Efficiency Program

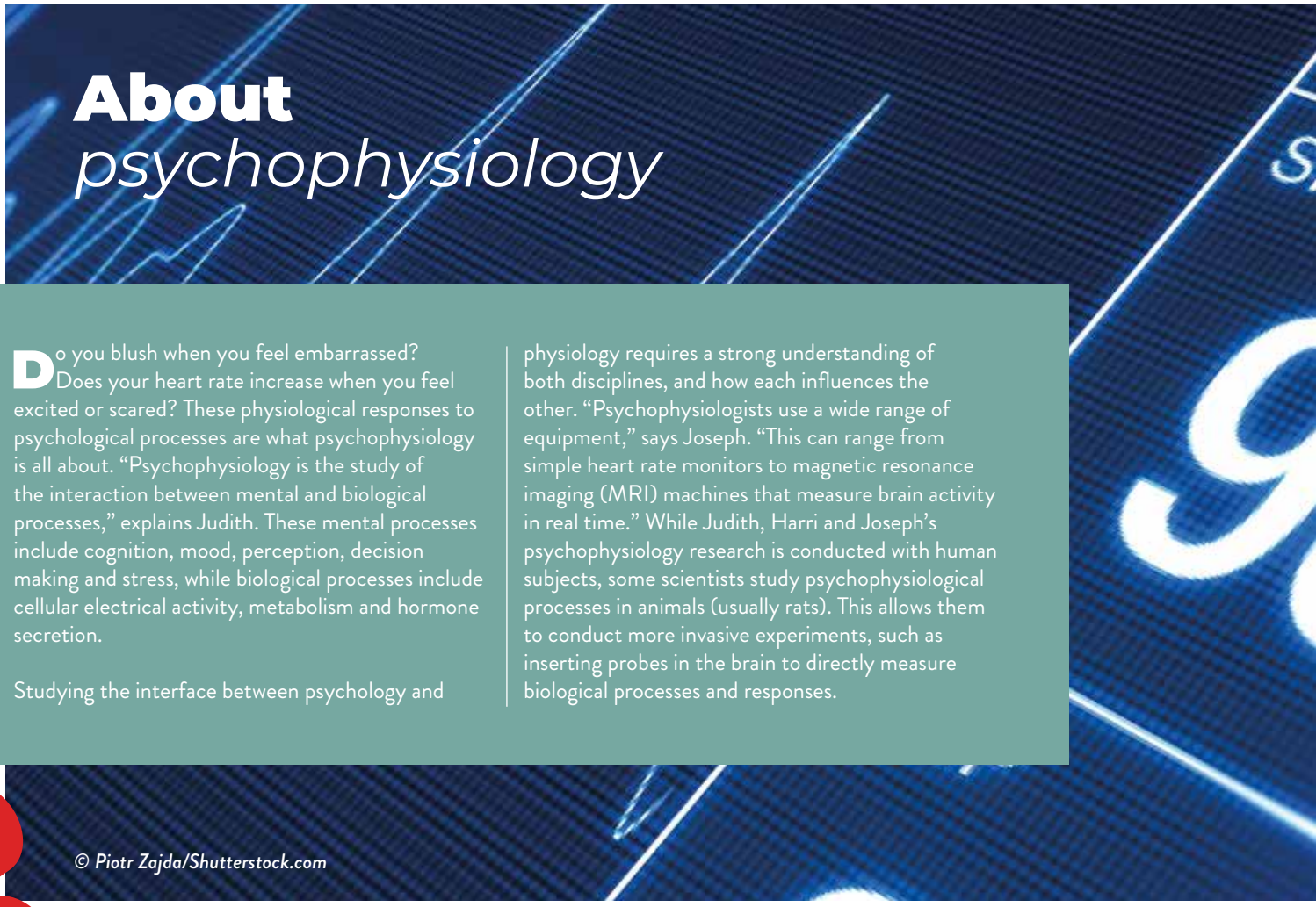
Judith, Harri and Joseph have now rolled out a police training programme that makes use of the lessons learnt from their research. "iPREP teaches officers about biological awareness and psychological and physical responses to their environment," says Harri. "Police officers often don't understand the link between these reactions and their performance – iPREP aims to change that."

iPREP training focuses on reality-based scenarios, using HRVB to help officers understand their body's reaction to stress and how this influences their decision-making process. Officers are then taught methods to gain better control over their stress response. "Any taught behaviour or skill that is performed during stressful situations needs to become an automatic response for officers," says Judith. iPREP has been fully accredited by the University of Toronto Temerty Faculty of Medicine and is now used to train police officers in North America and Europe.

About *psychophysiology*

Do you blush when you feel embarrassed? Does your heart rate increase when you feel excited or scared? These physiological responses to psychological processes are what psychophysiology is all about. "Psychophysiology is the study of the interaction between mental and biological processes," explains Judith. These mental processes include cognition, mood, perception, decision making and stress, while biological processes include cellular electrical activity, metabolism and hormone secretion.

Studying the interface between psychology and physiology requires a strong understanding of both disciplines, and how each influences the other. "Psychophysiologists use a wide range of equipment," says Joseph. "This can range from simple heart rate monitors to magnetic resonance imaging (MRI) machines that measure brain activity in real time." While Judith, Harri and Joseph's psychophysiology research is conducted with human subjects, some scientists study psychophysiological processes in animals (usually rats). This allows them to conduct more invasive experiments, such as inserting probes in the brain to directly measure biological processes and responses.



Pathway from school to *psychophysiology*

At school and beyond, study biology, chemistry, psychology and mathematics. "Psychophysiology blends understanding from lots of scientific areas," says Judith. "Key topics include human physiology, psychology, cognitive science, biochemistry, mathematics, statistics and neuroscience. These areas of study are necessary to understand the psychophysiological processes taking place and the methods that are used to analyse them."

Some universities offer degrees in psychophysiology. A degree in psychology, physiology or medicine could also lead to a career in psychophysiology.

Explore careers in *psychophysiology*

Some psychophysiologists work in academia, where they conduct research with human or animal subjects to understand how the body responds to psychological processes. Others have clinical careers, where they work with patients to help them manage their body's responses to psychological inputs.

Judith suggests contacting psychophysiology researchers at nearby universities and asking them about their research and whether they have any career advice or work experience opportunities.

The Society for Psychophysiological Research (**www.sprweb.org**) and the International Organization of Psychophysiology (**www.iopworld.org**) have information and resources about the field. When you start university, Judith recommends reading articles from the International Journal of Psychophysiology (**www.sciencedirect.com/journal/international-journal-of-psychophysiology**) and Psychophysiology (**www.onlinelibrary.wiley.com/journal/14698986**) to learn about current research topics (your university should have a subscription so you can access them).

Meet *Judith*

As a teenager, I had a wide range of interests. I was on the acro-gymnastics team, sang in a choir and loved being outside in nature as much as possible. My parents were in health and caring professions, and their influence caused my interest in psychology.

Growing up, my family moved every few years, so I experienced many different environments. Seeing the diversity of nature between Ontario, Arizona and California was a formative experience that began my love for health psychology. However, moving all the time was also very stressful and impacted my education. I was a shy child and sometimes experienced paralysing fear. Despite this, I sought out whatever assistance I could to support my learning. However, I always wished for more tangible ways to reduce my stress.

When several of my peers joined the military, I was amazed by their stories of facing extreme stress. During my master's degree in counselling, I completed an internship at a veterans' hospital where I met many soldiers and veterans with experiences of post-traumatic stress disorder (PTSD). Along with my own experiences, that inspired me to research ways to help people feel relief from stress while staying healthy and performing at a high level in their careers.

> ***"Growing up, my family moved every few years... which was very stressful. I always wished for more tangible ways to reduce my stress."***

As a psychophysiology and health researcher, I enjoy being embedded with teams of police officers in the field. I conduct research directly in the environments relevant to the people I'm working with. I've accompanied training exercises at military bases and measured physiological reactivity of federal officers while on duty and during advanced exercise courses. This gives me the opportunity to better understand the realities of these careers and to create tangible ways to reduce stress and boost health.

I am obsessed with gardening and enjoy listening to audio books. I also love taking my dogs on long hikes. My happiest days are a combination of all these activities!

Meet *Harri*

As a teenager, I lost interest in studying and did all kinds of stupid things. But then I discovered karate, which changed my direction entirely. Participating in martial arts helped me take responsibility at school and in my life and it awakened my curiosity in humanity's potential.

Growing up in northern Finland, I was surrounded by a unique blend of athleticism and adventure. My father was a renowned former elite discus thrower, and a steady stream of ex-athletes were always arriving at our doorstep. These visits often led to unforgettable hunting and fishing trips, with tales of past glory days. Many visitors were also police officers, giving me a glimpse into the world of law enforcement that seemed both thrilling and daunting.

I worked in the Finnish National Police Special Intervention Unit for over 20 years. When I joined, the unit was suffering after a failed hostage rescue operation and organised crime was spreading in the country. We had to react, but even though we developed our tactical procedures, training systems and operative management skills, we made too many mistakes.

> ***"I wanted to understand the mind-body connection behind stress in life-threatening situations."***

I wanted to understand why these mistakes happened. Why did stressful situations cause us to lose situational awareness and make bad decisions? I wanted to understand the mind-body connection behind stress in life-threatening situations. So I trained as a mental resilience coach, where I learnt that we must master our internal responses to stress.

Harri with Epi, his special unit attack dog

These days, my time is spread among many different activities. In addition to participating in scientific research projects, I am writing a book and I lead online coaching programmes and one-to-one coaching. I am an entrepreneur and every day is different, which I love.

In my free time, I love sports. I go to the gym and enjoy trail running in the forest. I also play music.

Meet *Joseph*

As a teenager, I wanted to understand how the world around me worked. I was fascinated by meditation and the link between body and mind. I studied martial arts, and the mind-body links formed through martial arts and meditation have been central to my life ever since.

I had a hard time choosing what to study at college. I settled on chemistry, but even after graduating, I wasn't sure what I wanted to do. I worked in a lab doing molecular genetics research, which was exciting and very new at the time, but I kept reading about psychology. I decided I wanted to learn how to apply the skills I had learnt from intense training in martial arts and meditation to healing people and teaching people to heal themselves. That led me to become a physician specialising in psychiatry.

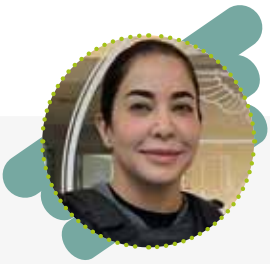
I use both medication and psychotherapy when working with my patients. We talk about their physical and emotional responses to internal and external experiences, and how to make those responses more helpful. I use biofeedback to help them get more control over their autonomic nervous system and to manage stress.

Many of my patients are healthcare professionals or first responders. They need techniques to perform effectively in high-stress situations. My martial arts and meditation training taught me many such techniques, and I am able to combine these with knowledge of psychophysiology to help patients respond effectively under stress.

I became aware of Judith's work with police officers after hearing her on a podcast. It linked with my clinical work, so I called her and we spent two hours talking about stress, physiology and its effects on performance. She invited me to work with her team and I am very glad to be doing so.

In my free time I enjoy reading, meditating, spending time with family and philosophising about life. I also love writing, especially about meditation and stress. I co-authored a book on meditation that received a foreword from the Dalai Lama!

Meet *the iPREP content contributors*



Sergeant Lissa Ruocco
Lissa has over 25 years of experience in law enforcement. She has spent 18 years in the tactical unit, working as a sniper (the first female sniper in all of Canada), negotiator, rappel master, fitness appraiser, team leader and training officer. Lissa loves to encourage people to pursue a career in tactical policing and has won the Ontario Women in Law Enforcement's Mentoring and Coaching Award.

Retired Senior Constable Steve Poplawski
Steve has over 30 years of experience as a police officer and use of force instructor. He has developed and taught evidence-based de-escalation techniques and has worked with many first responder groups. Steve has particular expertise in scenario-based learning and defensive tactics, including in criminal investigations and frontline operations.

Retired Sergeant Don Back
Don has over 30 years of experience in law enforcement, with extensive expertise in use of force training, legislation, and criminal and sexual assault investigations. He has worked as a use of force instructor at the Ontario Police College and the Canadian Police College, and he has particular expertise in scenario-based learning and defensive tactics.

Dr Paula Di Nota
Paula studies the complex relationships between learning, stress, performance and mental health in police and other public safety professionals. She has conducted field investigations using ambulatory HRVB with law enforcement officers in Canada and Europe, with the aim of improving physiological resilience, cognition and motor performance.

Retired Chief Gene Di Maria
Gene has over 25 years of community corrections experience, having served as a probation officer and supervisor, and he was instrumental in the development of the US Federal Probation and Pretrial Academy. He has worked as a use of force instructor, firearms instructor, defensive tactics instructor and scenario-based training instructor, and he served as chief of safety and firearms for the Probation and Pretrial Services Office of the US Courts.

Dr Juha-Matti Huhta
Juha-Matti has over 20 years of police experience, including in a K-9 (police dog) unit and a regional special response team. His scientific research focuses on understanding and developing situational awareness in policing and using evidence-based approaches to police training.

Navigating the maze of reading comprehension for first grade learners

At the **Université du Québec à Montréal**, Canada, **Dr Marie-France Côté** studies the complexities of reading comprehension among first grade French-speaking learners in Quebec. She is looking at the difficulties in assessing these early years students and working on a new and more reliable assessment tool called ESPACE.

Dr Marie-France Côté

Department of Language Didactics, Université du Québec à Montréal, Canada

PROFILE

Fields of research
Language didactics, reading

Research project
Investigating the ability to understand written texts among beginning readers during the first year of primary school

Funder
This work is/was supported by the Social Sciences and Humanities Research Council of Canada (SSHRC), under award number 430-2021-00872. The contents are solely the responsibility of the authors and do not necessarily represent the official views of SSHRC.

Talk like a ...

reading researcher

Anaphora — the use of a word referring to a word used earlier (or, sometimes, later) in a text to avoid repetition (e.g., the pronouns he, she, it and they)

Cognitive load — the amount of cognitive resource (such as working memory) required to perform a task

Explicit — when meaning is stated clearly

Grapheme — a written symbol of a phoneme (sound). This could be a single letter (such as 'e' in 'egg') or combination of letters (such as 'ee' in knee')

Implicit — when meaning is implied, rather than stated directly, and has to be inferred

Inference — drawing conclusions or making educated guesses based on information provided in the text and one's own background knowledge

Phoneme — smallest unit of sound in a given language

Reading comprehension — understanding the meaning of written text, including explicit and implicit information

The ability to read is not just about knowing words. It is about understanding stories and ideas; it expands our knowledge and guides us through the complexities of life. Among the many challenges faced in fostering literacy, understanding how young learners comprehend what they read is central. Many studies have already highlighted the crucial role of understanding written text and its profound influence on children's academic progress. "Quebec-based research[1] has shown that more than half of school dropouts experience significant delays or failures in reading at the time of dropping out," says Dr Marie-France Côté, a special education teacher at the Université du Québec à Montréal. "It is also known that a significant proportion of students, ranging from 20% to 30% in primary school, encounter significant difficulties in text comprehension."[2]

Marie-France and her team are studying reading comprehension among first grade French-speaking learners in Québec, developing a new assessment tool called ESPACE to detect and address these difficulties early on.

What challenges do beginner readers face?

For new readers, the journey of learning to read is like navigating a huge labyrinth of different words and meanings. It is a huge challenge — one that some say is the toughest cognitive task children face. When learning to read, children must make a

concerted effort to recognise printed letters, to associate those letters with sounds and then to master making these connections quickly. "The process for reading a word involves learning the code, which means learning the sounds of each letter or each combination of letters," explains Marie-France. "Children need to learn to map graphemes (letters) to phonemes (sounds) in order to be able to read written language." In languages like French and English, where words do not always sound the way you would expect them to from how they are spelt, things can get even more complicated. Consider the word 'knife', which defies its spelling when pronounced, as the letter 'k' is silent. For this reason, children need to show flexibility when reading, adapting to the diverse ways words are pronounced, despite their written form.

Why is the assessment of reading at first grade so difficult?

"In first grade, 6-year-olds are still learning to map letters into sounds, and it takes many cognitive resources to do so," says Marie-France. "Therefore, since our brain only has a certain amount of cognitive resources available at the same time (e.g., we cannot do five tasks at the same time), almost all the cognitive resource of young readers go to identifying words." This allocation of energy leaves limited resources available for comprehending the text's meaning once words are decoded. Consequently, crafting assessments for first grade readers requires careful consideration of the cognitive load imposed by word identification. For example, reading assessments should use a high proportion of easy-to-read, accessible words and a smaller proportion of harder-to-read words. Unlike older students who find word recognition easier, first grade students need simpler words to free up 'brainpower' for understanding the sentences and whole texts that they read.

> ***"Among the many challenges faced in fostering literacy, understanding how young learners comprehend what they read is central."***

According to Marie-France, it is also vital to assess both explicit and implicit information in reading comprehension assessments. While explicit information is directly stated in the text, implicit information requires readers to infer meaning, demonstrating higher-order cognitive skills. "Reading assessments need to assess a range of different abilities in students, in order to offer a rich overview of a student's ability to read (e.g., understanding simple versus complex sentences or explicit versus implicit information)," explains Marie-France. "It is important to be able to identify which abilities students possess or which abilities they find more difficult, and to intervene and help where necessary." For this reason, there is a great need for assessments that provide insights into various reading abilities, enabling teachers to personalise interventions to students' needs.

What is the ESPACE assessment tool?

ESPACE, the Évaluation Spécialisée des Premiers Apprentissages en Compréhension Écrite (specialised assessment of first skills in reading comprehension), is an assessment tool designed by Marie-France and her colleague Professor Line Laplante to measure the reading comprehension skills of first grade students. It consists of six texts that progress in complexity, taking into account the challenges young readers face in decoding words. The words in each text are carefully selected to match the students' ability to decode words, with simpler words in the earlier texts and more complex ones in the later texts. Additionally, the sentences in each text increase in complexity, and the associated questions target specific cognitive abilities, such as understanding anaphora and making inferences.

What insights has the ESPACE assessment provided?

This innovative assessment tool has already been tested and improved upon. It was used to evaluate students' comprehension of texts in February and June, two key assessment times in the school year, allowing researchers to track changes in understanding throughout the school year, especially from the middle to the end of the academic term. "Children's ability to understand texts improved between the middle and end of the school year," says Marie-France. "When looking at it in more detail, we observed that students did better in the June test on each question, even on those questions associated with higher level cognitive processes like inference. This shows

that some (more able) students can answer inference questions as early as in the middle of Grade one." However, performance varied across different text complexities, with students generally struggling more with complex texts.

One of the most interesting aspects of Marie-France's research was the comparison of 'typical' and 'at-risk' readers. More specifically, students were categorised into three tiers based on their performance: low, average and high. Those in the low tier in February were considered 'at-risk'. "If we compare the average score of typical and at-risk readers for each question type, we can see that typical readers always have a higher score than at-risk readers in both the February and June assessments, meaning that typical and at-risk readers' comprehension differ greatly, no matter the type of questions," says Marie-France. "Interestingly, some students were at-risk in February, but improved enough to not be considered at-risk in June." This finding highlights the potential for growth and improvement among at-risk readers when provided with targeted interventions and support.

How could ESPACE be used in schools?

The ESPACE assessment holds great potential for enhancing literacy instruction in schools. By serving as a universal screening measure for first grade students, it enables early identification of those at risk of reading comprehension difficulties. "For example, a teacher noticing that the majority of students in her class struggle with certain questions requiring the implementation of a specific process could plan lessons aimed at the gradual development of this process during activities offered to all her students," says Marie-France. This is what makes ESPACE so promising: teachers can tailor interventions based on students' specific needs, fostering skill development and mastery. With its multiple uses and ability to track progress over time, ESPACE empowers educators to provide targeted support and ensure all students receive the necessary assistance to succeed in reading comprehension.

[1] **https://statistique.quebec.ca/fr/fichier/les-eleves-du-primaire-a-risque-de-decrocher-au-secondaire-caracteristiques-a-12-ans-et-predicteurs-a-7-ans.pdf**

[2] Vaughn, S., Wanzek, J., Woodruff, A. L., & Linan-Thompson, S. (2007). Prevention and early identification of students with reading disabilities. In D. Haager, J. Klinger, & S.Vaughn (Eds.), Evidence-based reading practices for response to intervention (pp. 11-27). Baltimore: Paul H. Brookes Publishing Co.

About *language didactics*

Language didactics is a field dedicated to the teaching and learning of languages, particularly within educational settings. It covers how people learn languages, develop reading and writing skills, and the best ways to teach languages effectively. Researchers in this field investigate how individuals acquire, process and use language skills, with a particular emphasis on effective instructional methods.

Language didactics is an important field that focuses on improving how children learn to read and write. "Knowing I can help improve children's school journeys by developing assessments that can improve our understanding of their difficulties or conceive interventions that can help them better learn to read makes this career extremely rewarding," says Marie-France. "It is also fulfilling to discover new information about how kids learn to read and share them with other researchers who share the same passion."

For the next generation of language educators, there are many research opportunities waiting to be explored. "For example, conceiving and testing new interventions that could help children of all ages better learn to read and write, or investigating the best teaching practices for reading comprehension, vocabulary, grammar and spelling," says Marie-France. Additionally, new issues are emerging in language education, such as the role of artificial intelligence (AI). "What role could generative AI play in education when it comes to learning to read and write? Could AI teach 'better' than an actual person? Could it assist a teacher by evaluating a student or grading papers?" says Marie-France.

Explore careers in *language didactics*

"You can read scientific articles and attend conferences about language didactics," says Marie-France. "The Society for the Scientific Study of Reading (SSSR) is a big scientific association". It offers resources, conferences and publications for researchers and practitioners in the field of reading and literacy: **www.triplesr.org**

"Any resources aimed at informing teachers about how they can better teach reading and writing is a good starting point," says Marie-France. For example, The British Council provides free resources to teachers: **www.teachingenglish.org.uk/professional-development/teachers/managing-lesson/teaching-reading-and-writing**

Some useful websites include the International Literacy Association (ILA) (**www.literacyworldwide.org**) and TESOL International Association (**www.tesol.org**) which provide professional development resources, publications and conferences focused on literacy education and research, and professional development opportunities for educators working with English language learners respectively.

Average salaries for language educators in elementary schools and universities in Canada range from $60,000 to $100,000.

Pathway from school to *language didactics*

To pursue a career in language didactics, it is beneficial to study subjects that provide a strong foundation in language, education and communication, such as English, social sciences and foreign languages.

"In university, a degree in education (elementary or high school) or in linguistics can lead to language didactics," says Marie-France. "To be a research assistant, you will at least need a master's degree. To become a professor and pursue your own research projects, you will need a PhD."

"Some researchers have a background in educational psychology and specialise in the study of learning to read and write," explains Marie-France.

Some language schools, educational institutions and language departments at universities offer internships for high school students interested in language didactics. Check with local universities, language institutes or language education organisations to inquire about internship opportunities.

Language didactics is an important field that focuses on improving how children learn to read and write.
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Q&A

Meet *Marie-France*

Who or what inspired you to become a researcher in education and language didactics?

I first wanted to become a special education teacher to help kids that experience difficulty learning. After my bachelor's degree, I didn't feel ready to take on the responsibility of teaching a whole class of students with different educational needs, so I decided to complete a master's degree in special education, with a specialisation in reading and writing.

During my academic journey, I fell in love with the process of doing research. I found other researchers and the possibility of improving teaching approaches very inspiring, and I love the creativity associated with the design of a research project. I also like doing a large range of tasks as a researcher (teaching future teachers, collecting research data among elementary school students, analysing data with diverse methods, participating in policy development, writing scientific articles, etc.).

What experiences have shaped your career?

Working with my research supervisors, both for my master's degree and PhD, inspired me a lot. Then, giving my first speech in front of a crowd full of teachers and researchers and receiving great comments about my presentation was very empowering.

What are your proudest career achievements so far?

Developing the ESPACE assessment tool and seeing it being so appreciated by teachers in schools. Additionally, publishing scientific papers in journals and conferences I used to read/attend before becoming a professor. Collaborating in research projects with international researchers I used to admire when doing my doctoral studies has also been a particularly gratifying aspect of my journey in academia.

What are your aims for the future?

To develop more assessment and interventions that can help students experiencing difficulties better learn to read and write and share findings and the best teaching methods with teachers in elementary schools, so they can have the best tools to help students.

Marie-France's *top tips*

1. Follow your passion and work hard.

2. Don't hesitate to contact researchers and ask questions – we are always happy to answer questions and talk about our work.

Can embracing plurilingualism transform education?

Dr Caroline Payant, an applied linguist at the **Université du Québec à Montréal** in Canada, is exploring the power of plurilingualism – the use of multiple languages – in language education. She highlights the potential of plurilingualism to reshape not only our classrooms, but also our perceptions of language, culture and identity.

Dr Caroline Payant

Department of Language Teaching, Université du Québec à Montréal, Canada

PROFILE

Fields of research
Applied linguistics, plurilingualism in language education

Research project
Exploring the importance of plurilingualism in language education

Funders
Social Sciences and Humanities Research Council of Canada (SSHRC/CRSH); Fonds de recherche du Québec – Société et culture (FRQSC); Faculty of Education at Université du Québec à Montréal

Talk like an ...

applied linguist

Input — the information that an individual receives (e.g., hearing speech or reading text)

Language repertoire — the collection of (partial) language knowledge that someone has access to in order to communicate with others

Monolingual approach — a language teaching method in which only the target language is allowed to be used in the classroom

Plurilingual approach — a language teaching method that acknowledges and embraces all the linguistic knowledge that students have access to

Plurilingualism — the ability to understand and communicate in multiple languages, embracing the rich diversity of languages and cultures

Imagine stepping into a classroom where every language spoken by each student is not just tolerated but celebrated – a place where linguistic diversity is not viewed as a barrier but as a bridge to deeper understanding and connection. In today's globalised world, the ability to communicate across linguistic divides is not just a valuable skill but a necessity, and the role of language in education has taken on new significance. Language is a tool for exchanging ideas and forming relationships, and it is the foundation for sharing cultures and respecting each other.

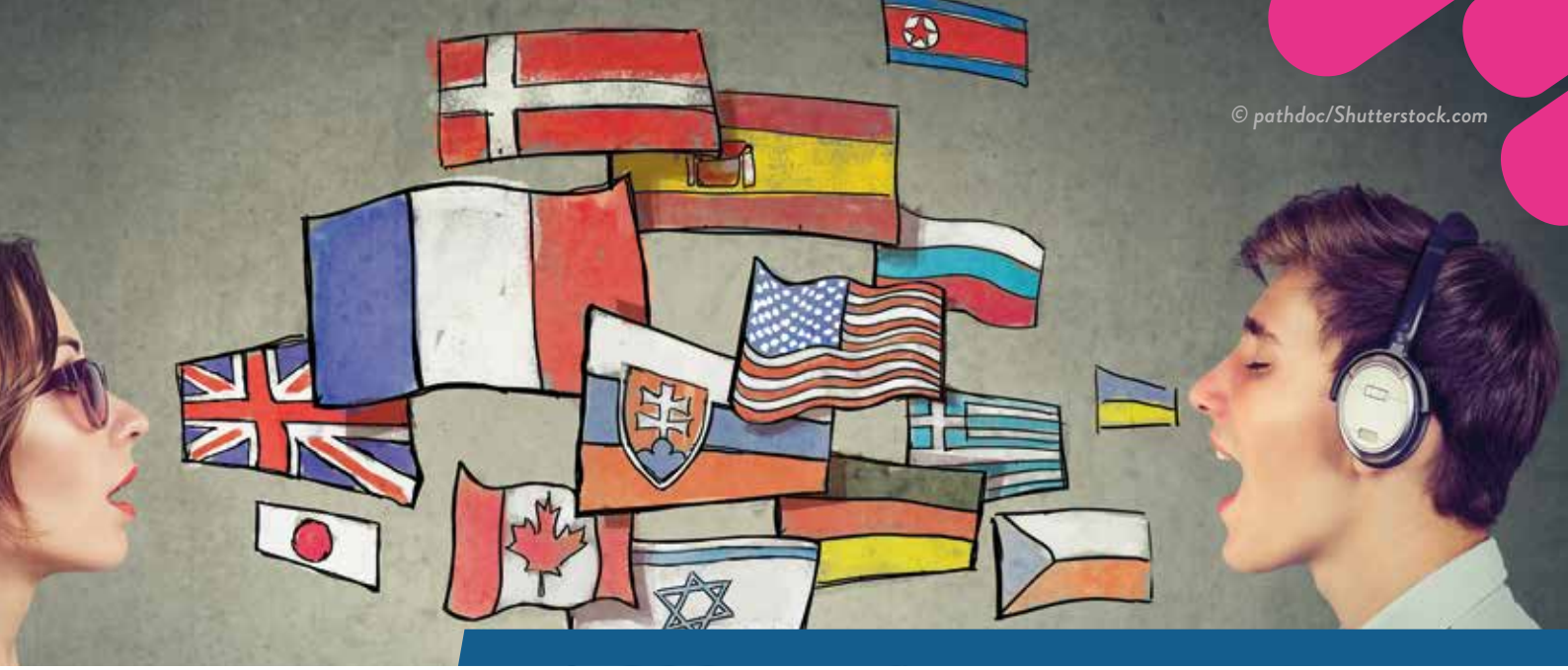
What is plurilingualism?

Dr Caroline Payant, an applied linguist and language teacher educator at the Université du Québec à Montréal, is reshaping language education by advocating for plurilingual teaching approaches. "Plurilingualism, as both a theoretical perspective and an approach to language teaching and learning, focuses on exploring an individual's holistic language repertoire," explains Caroline. "Their repertoire may include knowledge of multiple languages, each with varying levels of proficiency."

Plurilingualism is more than just speaking multiple languages; it is about embracing the rich diversity of languages and cultures that defines each of us. Each language we speak offers a unique window into aspects of our culture and ways of thinking. It is this diversity that enriches our understanding of the world and allows us to connect with people from different backgrounds.

How does your language repertoire influence your identity?

Our language repertoire is profoundly connected with our sense of self and belonging. The languages we choose to speak in different situations reflect not



only where we come from, but also our personal experiences and cultural heritage. Each language carries a unique set of associations and emotions which shape how we express ourselves and perceive the world around us.

Our language repertoire can also influence how other people view us, as our choice of language might cause some people to make assumptions about aspects of our identity, such as social status or level of education. "Languages are social constructs with varying degrees of prestige," says Caroline. "Societal perceptions of our linguistic choices can positively or negatively influence how we perceive ourselves and how others view us. In an ideal world, all languages and their speakers are treated equally, but the reality is marked by pervasive inequalities." Recognising the complex relationships between language, society and identity is crucial for creating more inclusive linguistic environments where individuals feel empowered and respected regardless of the languages they speak.

What are the arguments for and against a monolingual approach in language education?

The use of a monolingual approach in language education is a key topic of debate. Many language teachers believe that only the target language should be spoken in the classroom – all instruction and communication should be in the target language and students should never use their first language in additional language classes. "Support for a monolingual approach stems from the belief that language development mirrors the natural process of acquiring a first language," says Caroline. "Advocates argue that the role of input is pivotal and emphasise that providing exclusive input in the target language is essential for language learning."

However, Caroline believes that a monolingual approach is not the best way to help students learn. "When you learn a new language, it's impossible to ignore the languages you already know," she explains. "There is strong evidence that all languages are activated during social interactions. As such, you can use what you know in one language to help you understand and learn another."

How does plurilingualism impact learning?

It is important for all students to feel accepted in the classroom. "A monolingual stance can inadvertently reinforce societal ideologies that assign greater importance to certain languages over others," says Caroline. "This perceived hierarchy needs to be deconstructed." To create a fairer world, we need to recognise and celebrate the value of all languages and the diverse cultures they represent by embracing a plurilingual approach to language education.

Plurilingualism cultivates an inclusive learning environment where students are encouraged to explore their linguistic diversity. In Canada, for example, while most people can communicate in English and/or French (the country's official languages), in 2021, 25% of Canadians reported having a different language as their first language (Mandarin and Punjabi being the most common). Canada also has also over 70 Indigenous languages, spoken as a first language by <1% of the population.

In language classes, Caroline invites learners to engage with their various languages through creative activities such as language portraits, which connect languages to body parts and personal experiences. "For instance, in my case, when I think of French, I think of my heart," she says. "I associate this language with my family, roots and heritage." This approach encourages students to embrace all the languages they know.

What has Caroline discovered?

Caroline's research on the importance of plurilingualism in language education reveals significant insights into both student and teacher perspectives. "Learners express a sense of value and motivation when their various languages are acknowledged and encouraged," says Caroline. "Conversely, when restricted from using their languages at school, a feeling of insecurity or disrespect emerges."

Teacher attitudes towards plurilingual approaches still vary. Some believe students will be confused if multiple languages are spoken in the classroom, while others recognise the importance of valuing all students' backgrounds and have developed creative activities that highlight students' language repertoires. Caroline is determined to deconstruct the myths around monolingual and plurilingual approaches and to educate teachers on how best to support their students and create an inclusive educational environment.

About *applied linguistics*

Applied linguistics explores the practical applications of linguistics – the study of languages and their structures. It encompasses areas such as language teaching, language policy and sociolinguistics. Applied linguists study how languages are learnt, taught and used in different contexts.

How can plurilingualism promote social justice?

"Plurilingualism plays a very important role in promoting social justice, diversity and inclusion by challenging the ideology that there is a 'right way to speak'," says Caroline. "This ideology designates one language or language variety as 'correct', while marginalising others as 'inferior'." By recognising and valuing the diverse language repertoires of individuals and communities, plurilingualism challenges these colonial linguistic hierarchies. Plurilingualism has the potential to create a more inclusive and equitable society where all languages and cultures are respected and celebrated.

Why is it important to learn about cultures when learning languages?

Learning a new language goes beyond acquiring linguistic skills; it also involves understanding the culture(s) associated with that language. "The study of culture, which is by no means simple, enables exploration of values, ways of being and societal norms through language," says Caroline. "This holistic approach enriches language development. It offers insights into the beliefs, traditions and history of the language community and fosters a deeper connection with the language and its people."

Pathway from school to *applied linguistics*

At school and beyond, take classes in your country's official language(s) and in foreign languages. These will introduce you to linguistic exploration and give you an appreciation for the similarities and differences between different languages. Study the culture and literature of the languages you learn to gain a deeper understanding of them.

Communicate with speakers of different languages to learn more about the cultures associated with them and to practise your language skills. If possible, talk with family, classmates and neighbours who have a different first language to you, watch films and TV shows in different languages, and if you travel somewhere with a different language, learn words and phrases and use them to communicate with local people.

Look for volunteer opportunities in your community or online that involve language-related tasks. This could be tutoring immigrants in your country's official language or working with organisations that promote language education.

At university, study linguistics or a language degree, followed by a postgraduate degree in applied linguistics. "Start by taking theoretical linguistic courses," advises Caroline. "These provide a formal study of languages from around the world, offering a comprehensive understanding beyond your country's official language." Specialised courses in sociolinguistics will cover how language interacts with society, culture and identity, while courses in computer programming will be useful if you are interested in developing language technology, such as language learning apps or translation tools.

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Explore careers in *applied linguistics*

A career in applied linguistics offers diverse opportunities in fields such as language teaching, curriculum development and language technology development.

Caroline recommends exploring the work of plurilingual researchers, such as at McGill University (**www.mcgill.ca/plurilinguallab/resources**) and Université de Montréal (**www.elodil.umontreal.ca**).

Teaching English to Speakers of Other Languages (TESOL) provides a wealth of information about careers in language teaching: **www.tesol.org/careers**

Meet *Caroline*

French is my home language – the language I spoke growing up in my home. But, living in a bilingual Canadian city, I had the privilege to learn English at school and in the community. When I moved to Mexico for work, Spanish and English became my main languages for work and social interactions. Because I wasn't speaking much French, I became insecure about my abilities when I did communicate in French – I felt I was no longer 'good' at speaking it. Now, I understand that I should never feel insecure about my languages and am proud to use my whole language repertoire whenever possible with as many people as possible.

My journey into applied linguistics was initially sparked by an interest in psycholinguistics because I wanted to understand how the brain processes two languages. While studying in Mexico, I explored how bilinguals mentally organise words. Over time, my motivation evolved towards using this knowledge to enhance learning experiences for students learning additional languages.

For my postgraduate research in the US, I questioned whether learners drew on knowledge of their first or second languages when learning a third language. This revealed that students made judicious use of their other languages, which was positive. But it also revealed teachers' resistance towards incorporating their students' first languages in the classroom. Many language teachers inadvertently encouraged students to reject their plurilingual identity and become 'monolingual' in two languages. This realisation troubled me, and I became determined to dispel the myth that using a first or second language in the process of learning additional languages would have detrimental effects on the student's experience.

During the pandemic, I started learning the Korean alphabet, Hangul, with the language-learning app, Duolingo. I loved the cognitive challenge but felt I needed to learn with peers to interact in the language, so I now take formal Korean lessons in Montreal. To practise, I communicate with my Korean friend, read children's books in Korean and watch Korean videos for children. I also type Korean sentences into Google translate to obtain the French or English translations, a plurilingual strategy, which allows me to practise my productive skills as I'm forced to create output in the target language.

When I am not working, I enjoy walking with my poodle, gardening and boxing. I also love snowboarding and I enjoy playing board games as this gives me the opportunity to spend quality time with family and friends.

Inspiring – and valuing – young women and non-binary people

As North West Regional Advisor for the **Stemette Futures Youth Board** in the UK, A-level student **Rachel Ryan** is helping to inspire girls and non-binary people to pursue STEM. From visiting local schools to discussing curricula with exam boards, she is a young leader highlighting that "dreams are attainable".

STEMETTES

What motivated you to join the Stemette Futures Youth Board?

I saw the opportunity advertised by the Stemette Society, a social network for young girls, women and non-binary people aged 13 to 25. I am aware that lots of national organisations tend to be London/southern-centric so when I saw the chance to give a voice to my region and provide more opportunities to North West England by working alongside Stemettes to promote engagement, it seemed like a no-brainer.

How do you think girls and non-binary people are currently feeling about STEM?

I have visited lots of schools in my region and, despite any opposition that young girls and non-binary people have faced from peers and societal expectations, those I have spoken to throughout my time on the youth board have a clear passion for STEM. They really value the work that Stemettes does to broaden their view of STEM fields and provide them with role models that show them their dreams are attainable. Young women and non-binary people are aspirational.

What did your work on the Stemettes' white paper on 'Equitable Curriculum Reform' involve?

The white paper on 'Equitable Curriculum Reform' is a remarkable Stemettes initiative that I am honoured to have played a part in. Two days after finishing my GCSEs in June 2023, I attended the Newcastle 'roundtable' to represent the youth board for North England and discuss the subject of diversity and inclusion in GCSE and A-level curricula (in the UK, curricula for 14 to 18-year-olds). This event was truly inspirational, and I was able to meet people from exam boards (such as OCR and WJEC) and the British Science Association, as well as the MP (member of parliament) for Newcastle and many others. It was fascinating to hear their thoughts on the subject and to have the opportunity to give my own thoughts as a young person studying A-levels.

What did you learn from this experience?

Mustering up the confidence to give my own views alongside so many outstanding individuals was a challenge but one I valued greatly. Opportunities like these are ones I will treasure forever; they have shaped many of the skills I will take into my professional life. I think that someone like me having a seat at that roundtable shows that, above all, Stemettes values the opinions of the young women and non-binary people who are interacting with these curricula. At the moment, these curricula do not reflect our aspirations or provide us with the role models we need. I fully support the white paper put forward by Stemettes and am so proud of the individuals behind it.

What curriculum changes would you like to see?

The ideal of diversifying the mentioned scientists and mathematicians in A-level curricula is very important. The two years spent studying A-levels are when most people are making major decisions about their future; if the content you're interacting with on a daily basis makes it seem like you wouldn't belong in a particular industry or profession, it could put you off pursuing a career in that area. I think that a more diverse range of individuals taught in STEM curricula would open up more opportunities in the minds of future generations.

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In what way has your role on the Stemette Futures Youth Board challenged you?

Confidence didn't come naturally to me, but through my work on the youth board, I've had to network and communicate with various people, like students, trustees and partners. This has drastically improved my people skills. You would think that being much younger than most of the people I have worked with would make it harder for me to get my opinions across, but this has never been the case. Stemettes has always valued my views, which has helped me in other aspects of my life; I know that everyone deserves respect, and all perspectives are important.

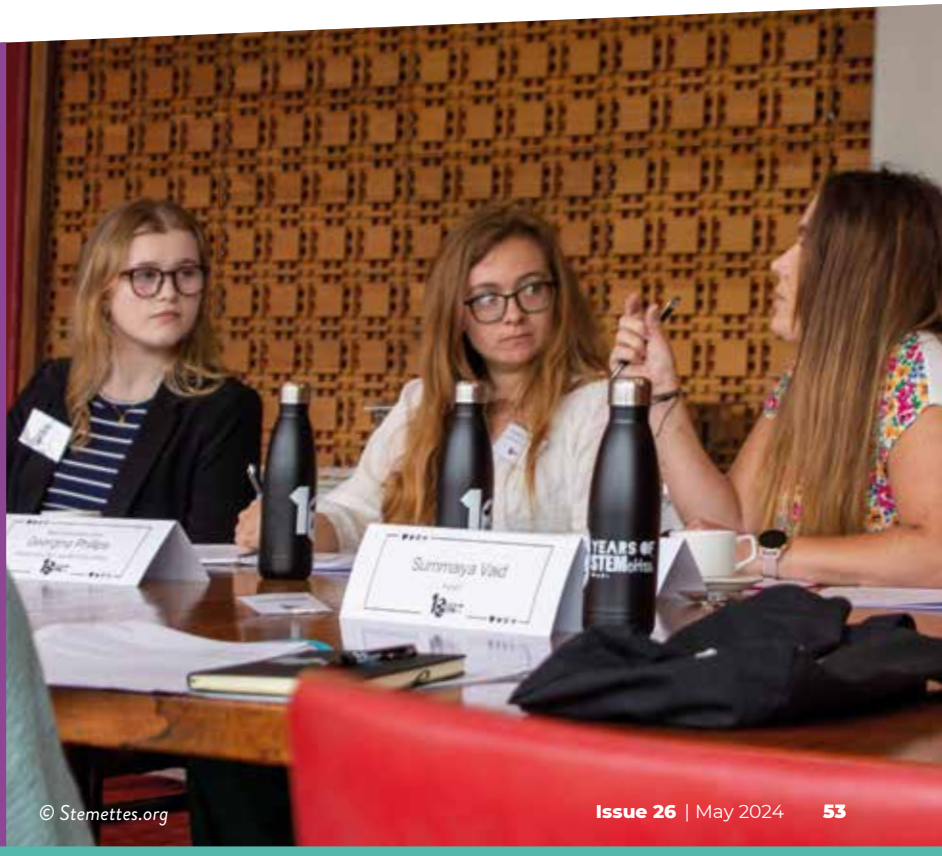
What is rewarding about your role?

The little things are very important to me – like hearing from a primary school I visited that a young girl has signed up for a Stemettes event, or getting a group of friends to sign up to the society together. Ultimately, I hope my work through Stemettes has made a positive difference in the lives of a few young people and opened up some doors to futures they didn't know were attainable for someone like them. That's what I really value.

What is your advice for anyone considering joining the Stemette society?

Absolutely go for it – the Stemette Society is such a supportive, inspirational environment, and there are so many amazing young girls and non-binary people with real passion for STEM that will welcome any new member with open arms. I have learnt so much from this group of people, and I've made friends that I value greatly.

> ***"Stemettes has always valued my views, which has helped me in other aspects of my life; I know that everyone deserves respect, and all perspectives are important."***



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The Stemette Futures Youth Board © Stemettes.org

> ***You've got nothing to lose by putting your name down for that work experience or event, so why not?***

About Rachel

I have always loved the problem-solving aspect of STEM, and I find it to be a very rewarding area of study – the logical methods to a (generally) definitive answer make sense to me. My passion for STEM has always come from my own interest rather than a specific moment or another person.

I relax through music – both listening to and performing it. I have sung from an early age, mainly solo, but I am also in my school choir. I'm also on track to do a diploma in popular music vocals. My musical extracurriculars are very important to me because a lot of them involve spending time with my friends, and they also provide a stark but necessary contrast to my STEM-focused studies.

Currently, I aspire to pursue a career in engineering – potentially, with a link to my interest in geography, such as energy or environmental engineering. Thanks to Stemettes, my passion for STEM just keeps growing!

Rachel's *top tip*

Take every opportunity you can, and do not allow self-doubt to hold you back. Signing up for interesting clubs/events, like those that Stemettes provide, has been such an important aspect of my life. You have to be mindful of not taking on too much, but if you play your cards right, you can end up with some really amazing opportunities. My thinking has always been – you've got nothing to lose by putting your name down for that work experience or event, so why not?

> ***I think that a more diverse range of individuals taught in STEM curricula would open up more opportunities in the minds of future generations.***

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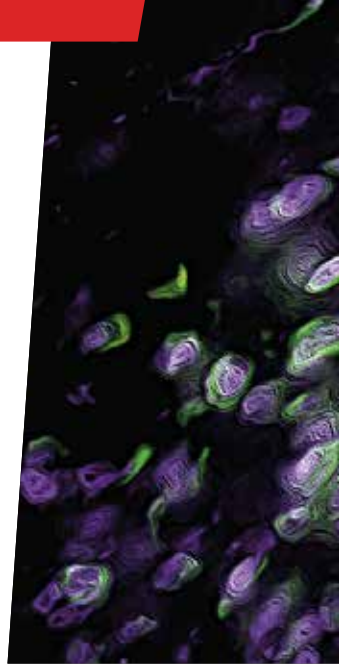
Connect with Stemettes

- Stemettes: stemettes.org
- The Stemette Society – for young women and non-binary people aged 13 to 25: stemettes.org/zine/stemette-society
- Stemettes Futures Youth Board: stemettes.org/youth-board
- linkedin.com/company/stemettes
- instagram.com/stemettes/?hl=en
- twitter.com/Stemettes
- www.youtube.com/user/Stemettes

Understanding leptin: how can changes in body weight affect reproduction?



Dr Carol Elias, a physiologist and neuroscientist at the **University of Michigan Medical School** in the US, is exploring how a hormone called leptin influences metabolism and reproductive health. She is seeking to uncover the mysteries behind conditions such as obesity, diabetes and infertility.

Dr Carol Elias

Department of Molecular & Integrative Physiology, University of Michigan Medical School, Michigan Medicine, USA

PROFILE

Fields of research
Neuroendocrinology, metabolism, obesity, diabetes, infertility

Research project
Investigating the neural basis of leptin action in reproduction

Funder
US National Institutes of Health (NIH)

Talk like a ... physiologist

Comorbidity — the existence of two or more related diseases

Leptin — a hormone produced by our body's fat, regulating energy expenditure, heat production, appetite and sexual maturation

Metabolism — the body's chemical process (happening in all our cells) of converting food into energy

Neural circuits — interconnected networks of neurons, the basic building blocks of the nervous system

Neuroendocrine — related to the release of hormones in the bloodstream

Physiological processes — the activities and functions that occur within living organisms to maintain life (e.g., metabolism, reproduction and digestion)

Puberty — the stage of development during which a person's body undergoes physical and hormonal changes, leading to sexual maturity and the ability to reproduce

Reproductive health — the state of complete physical and mental well-being in all matters related to the reproductive system, including its functions and processes, throughout the life cycle

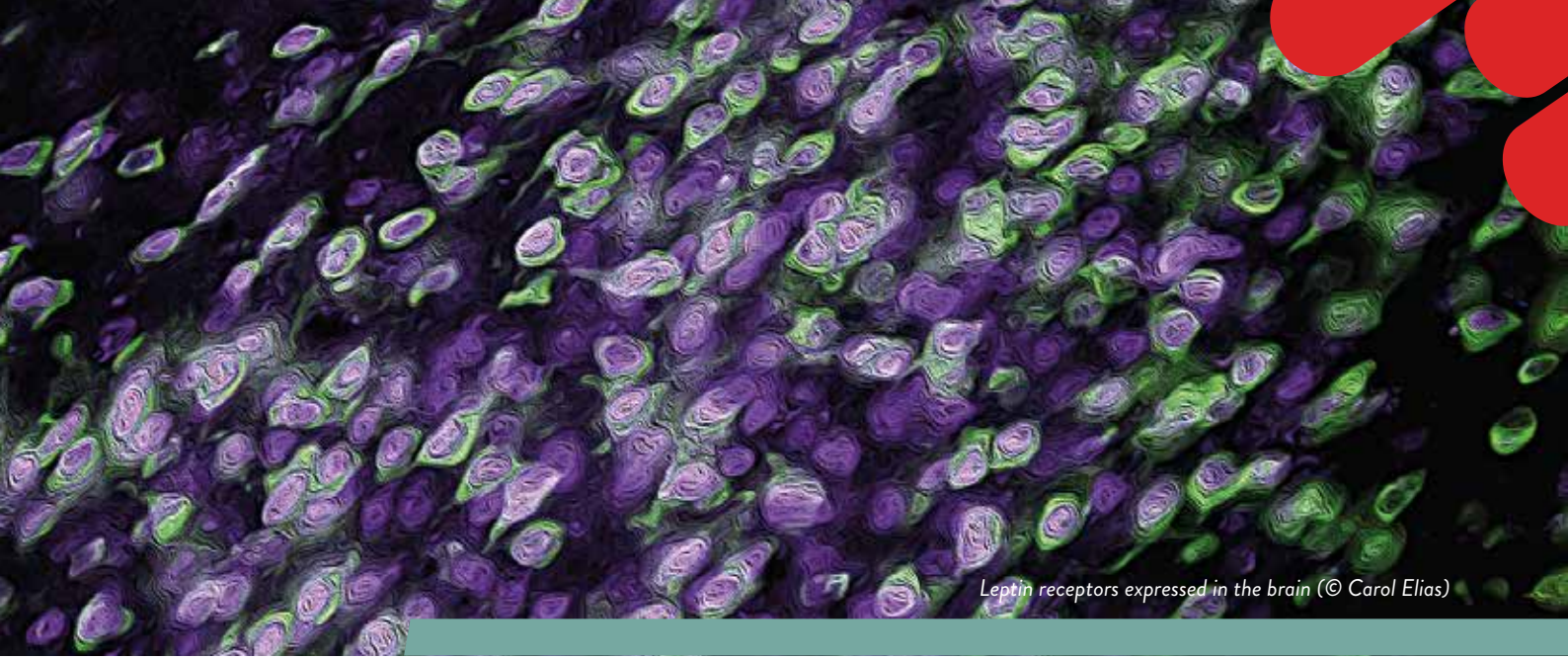
In the intricate symphony of our bodies, hormones take centre stage, regulating various physiological processes. These chemical substances act like messengers; after being made in one part of the body, they travel to other parts of the body where they help control how cells and organs perform their functions. Their influence can be of great significance, regulating everything from our metabolism to our reproductive health.

Among these remarkable molecules, leptin emerges as a key player, acting as a communicator between our body's fat cells and vital organs. When the delicate balance of this hormonal communication is disrupted, such as in conditions like obesity, it can affect how our body handles both metabolism and reproductive health.

Dr Carol Elias, a physiologist at the University of Michigan Medical School, is using a variety of molecular methods, such as genetics, to explore the neural basis of leptin action and its influence on metabolism and reproductive health.

A little bit about leptin

"Leptin is a hormone produced by our body's fat, or white adipose tissue," explains Carol. "It is secreted into the body's blood circulation and reaches organs and tissues where receptors are located." These receptors act as molecular 'docking stations', waiting for leptin's arrival to relay crucial messages. Once leptin attaches to its receptors, it sends signals which lead to regulated responses in the body. These responses affect metabolism, appetite and reproductive health. "Leptin has many different roles related to energy expenditure, heat production, appetite and sexual maturation, among others," explains Carol.



Leptin receptors expressed in the brain (© Carol Elias)

The diverse roles of leptin explain why its discovery was met with such enthusiasm. "The discovery of leptin in the 1990s was a significant moment for scientists in our field because it brought new possibilities to understand the cause and development of obesity, diabetes and diseases related to both, what we call 'comorbidities'," says Carol. "I was a neuroscience student at the University of São Paulo in Brazil at that time, and the excitement was huge because it turned out that the main site of leptin action is the brain." This discovery marked a turning point in scientific exploration, revealing the neural circuits that control energy balance and reproductive functions.

How can we study leptin?

Investigating the function of leptin involves combining laboratory techniques and genetic manipulation. More specifically, Carol and her team employ genetically-modified mouse models (mice that have been altered at the genetic level) to reveal the complexities of leptin's role.

These models can be created through two main approaches. The first method involves modifying a known or suspected disease-causing gene based on existing research findings. "If this gene is also found in mice, we can make modifications in this gene in the mouse and study the development of the disease and how we can treat it," explains Carol. "The other method is the inverse path, i.e., we make changes in a gene we do not know the function of and investigate what this modification results in for the mouse." If a disease occurs, this information is then used by other scientists to investigate whether a similar gene mutation is observed in humans with a comparable condition. Carol's research focuses on factors associated with infertility, obesity and diabetes. By modifying specific genes, Carol and her team can observe the resulting physiological changes in the mice, offering valuable information about leptin's function.

Brain mapping is a set of neuroscience techniques used to create a map of the brain's structure and functions. This can involve identifying and understanding different regions of the brain and how they are connected, as well as determining the specific tasks or activities each region is responsible for. "To understand how the neurons are connected and how these connections generate a specific response related to hormone secretion or behaviour, we use what are called neuronal tracers," says Carol. "These are molecules that enter the neurons and are transported through the axons (nerve fibres) to the terminals (where one neuron communicates with another via synapses)." By injecting neuronal tracers into specific areas of the brain and then examining their distribution using specialised tools, researchers can get important information about the brain's intricate wiring. "Using this approach, we have learnt that many parts of the brain are connected in the metabolic control of reproduction," explains Carol.

How does leptin connect energy to puberty and fertility?

"Our studies showed that leptin is one of the main hormones that signals energy availability to the brain," says Carol. This communication plays a dual role: guiding the path of pubertal development and influencing the balance between energy storage, weight and fertility. "If not enough energy is available, the organism has a way to block reproduction," explains Carol. "On the other hand, an excess of energy (i.e., obesity) may also decrease fertility because high levels of circulating hormones produced by the adipose tissue (e.g., leptin) may result in resistance, where cells fail to respond." This highlights the intriguing link between metabolic health and reproductive health and emphasises the importance of hormonal balance for optimal fertility.

What has Carol's team discovered?

Researching which parts of the brain connect metabolism and reproduction, Carol's team has already discovered specific groups of neurons that can detect leptin and respond to control the neuroendocrine reproductive function.

Carol's next steps include exploring the role of sex hormones, particularly testosterone, in the regulation of metabolism, and investigating the effect of childhood obesity in brain development and how it might shape the neuroendocrine response in adult life. These initiatives represent a frontier of discovery, set to reveal crucial insights into the complexity of hormonal regulation, metabolic pathways and reproductive functions.

About *molecular and integrative physiology*

Molecular and integrative physiology focuses on understanding how the molecular mechanisms within living organisms contribute to their overall function and how these mechanisms integrate at various levels to maintain health or respond to challenges. "Basically, the field focuses on how the body works and what happens when things go wrong causing a disease," says Carol.

The research within this field spans diverse areas such as cardiovascular (related to the heart and blood vessels), renal (kidneys) and gastrointestinal (stomach and intestine) physiology, as well as neuroscience. "My lab focuses on the brain and the neural circuitry and molecular pathways that connect metabolism and the neuroendocrine system," explains Carol.

This dynamic field reveals the complexities of cellular processes and their integration into the larger physiological context allowing you to learn something new every day. "Research in my field is very rewarding because we learn a new lesson on how the brain works every day," says Carol. Looking forward, the next generation of neuroscientists will find a variety of research opportunities available to them. "The last decade has seen an enormous development in neuroscience, mostly due to the development of new technologies," explains Carol. From the use of computational models to bioinformatics and machine learning, these technological advancements not only provide useful information about the brain but also present novel avenues for exploration and discovery.

Pathway from school to *molecular and integrative physiology*

"I believe students in all scientific fields will need a good training in coding, programming, computational modelling and 'best practices' for the use of artificial intelligence," says Carol.

To prepare for a career in physiology, it would be beneficial for high school students to take a combination of science and computational courses (such as biology, chemistry, mathematics, programming and computer science).

At university, pursuing a bachelor's degree in physiology, neuroscience or biochemistry is an excellent starting point.

Identify researchers in the field of physiology, especially those whose work aligns with your interests. Visit their university websites and explore opportunities of internships and lab experience.

Explore careers in *molecular and integrative physiology*

Carol recommends exploring websites such as the Society for Neuroscience (**www.sfn.org/outreach/brainfactsorg**), the Endocrine Society (**www.endocrinology.org/outreach**), and the American Physiological Society (**www.physiology.org/career/teaching-learning-resources/educator-resources/outreach-resources-and-publications?SSO=Y**).

"The University of Michigan offers many wonderful opportunities for students to learn about science and careers in science," says Carol. "For example, undergraduate opportunities (**medicine.umich.edu/dept/molecular-integrative-physiology/education/undergraduate-opportunities**), the Centre for Educational Outreach (**www.ceo.umich.edu**), Science Engagement and Education for Kids (SEEK) (**medicine.umich.edu/dept/molecular-integrative-physiology/education/outreach**), the Neuroscience Undergraduate Research Opportunity (NURO) (**www.neuroscience.med.umich.edu/neuroscience-undergraduate-research-opportunity-nuro**), and the Summer Intensive Research Experience in Neuroscience (SIREN) (**www.neuroscience.med.umich.edu/reu-site-summer-intensive-research-experiences-neuroscience-siren**)."

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Meet *Carol*

I always liked learning about the human body, animals and nature. In college, my major was in biological sciences. During a physiology class, I learnt about the brain and how neurons are connected to generate behaviour or body function. I fell in love with studying the brain and learning more about its huge complexity and how it functions in health and diseases.

During college years, I worked as research assistant in the physiology and cell biology departments. The brain was always my passion, so I did my PhD in neuroscience. During my PhD, I worked on the microscopic anatomy of brain tissue and methods of labelling neurons with fluorescent markers. I used to spend hours on the microscope looking at neurons, their different morphology, dendrites and axons. A special moment came with the discovery of leptin. Until then, we did not know the adipose tissue worked as an endocrine gland and that its main target was the brain. This information fascinated me.

Every small achievement in my career has made me proud because each has been necessary to reach my goals. Two important achievements for me were being accepted for a postdoctoral fellowship at Harvard University and being hired by the University of Michigan. The first because it opened the doors for high level research, and the second because it meant a recognition of my potential as an independent researcher.

It is important to emphasise that we do not do science alone. My lab has been fortunate with exceptional students and fellows. Some, like Judney Cavalcante, Jose Donato Jr. and Renata Frazao, David Garcia-Galiano, and Xingfa Han, now lead their own productive research in Brazil, Spain and China, respectively. Additionally, Beatriz Borges, Cristina Saenz, Ally Cara and Bethany Beekly are young scientists in the initial steps of their careers. Mentors, collaborators and assistants have also been very important for the success of my research. Jackson Bittencourt (University of São Paulo), Cliff Saper (Harvard University), Joel Elmquist (University of Texas Southwestern Medical Center), Sue Moenter and Martin Myers (University of Michigan) and Susan Allen (my lab manager for 10 years) have all been fundamental to my career.

Currently, I am involved in two important projects. One is as director of the Neuroscience Graduate Program, to which I dedicate 40% of my time to ensure students are well trained and prepared for the next steps of their career. The second is as director of a national centre associated with the National Institutes of Health. It provides analysis of changes in metabolism of experimental mouse models used by laboratories around the country in studies of diabetes and obesity. The main goal of this centre is to improve access to state-of-the-art technology to researchers from underrepresented groups or from institutions without consistent and significant funding for research.

Carol's *top tips*

1. Believe in yourself and be open to opportunities.
2. Go beyond your comfort zone.
3. Take some risks, be patient and prepare yourself for the next steps.

How can targeted antibodies and vaccines be used to treat cancer?

Causing nearly one in six deaths worldwide in 2020, cancer is one of the biggest health challenges of our time. Advancements in technology have led to improved treatments, one of which is using the body's immune system. **Dr Zachary Hartman** of **Duke University's School of Medicine** in the US is researching how to improve this approach and whether it has the potential to treat a variety of cancers.

Dr Zachary Hartman

Duke University School of Medicine, Department of Surgery, Duke University, North Carolina, USA

PROFILE

Fields of research
Surgical sciences, immunology, pathology

Research project
Understanding and enabling effective anti-tumour immunity from targeted antibodies and vaccines using innate and adaptive immune checkpoint blockade

Funders
US National Institute of Health (NIH), Department of Defence, Susan G. Komen, American Cancer Society (ACS)

Talk like an ...

immunologist

Adaptive immune system — the specific or acquired immune system

Antibody — a Y-shaped protein found in the blood used by the immune system to identify and neutralise foreign objects, such as bacteria

Antibody-drug conjugates — an antibody with a drug attached

Antigen — a foreign substance or surface marker that stimulates an immune response

Autoimmunity — the immune system's response against an organism's own cells

Chemotherapy — a form of cancer treatment using chemicals to kill cancer cells

HER2 — a gene coding for the HER2 protein that, in breast cells, helps with normal growth and repair but can function incorrectly and cause the cells to keep growing

Immunology — the branch of medicine and biology concerned with immunity and the immune system

Innate immune system — the non-specific immune system, the first line of defence

In vivo — performed or taking place in living organisms

Macrophages — specialised cells that play a role in the innate immune system

Monoclonal antibody — identical copies of one type of antibody that target a specific cancer antigen

Cancer is a common health issue, with one in two people being diagnosed with some form of cancer every year. One factor that makes the condition so challenging is its ability to evade the immune system, something made easier due to cancer originating from a person's own cells. This means that cancer cells have 'self' antigens, which the immune system recognises to be part of the body, as opposed to 'foreign' antigens, which the immune system recognises and attacks to prevent harm. Although the immune system will not attack cancer cells on its own, past research has shown that the immune system can be 'tricked' into registering the cells as foreign and attacking them. This is how antibodies came to be used to treat cancer.

Breast cancer is the most common cancer, making up 12.5% of cancer cases worldwide. So, it is no surprise that a wide range of research has been conducted on breast cancer. This research has identified that breast cancer is composed of different subtypes, which are driven by different types of genes and mutations. One

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subtype of breast cancer, which is very aggressive and rapidly growing, is defined by an amplification of the HER2 gene, classified as HER2 positive (HER2+) breast cancer. This also happens to be one of the only solid tumour cancers treated with tumour-targeting antibodies. At Duke University Medical School, Dr Zachary Hartman is researching how HER2 makes this cancer aggressive, how these HER2-targeting antibodies fight cancer, if these treatments can be improved upon and if there are any other cancer types that this type of treatment could be used for.

How is HER2+ cancer treated currently?

The standard HER2+ cancer treatment starts with chemotherapy and two monoclonal antibody treatments targeting HER2. If the tumour remains contained to the breast tissue, these treatments will be used until the tumour can be removed surgically. The chemotherapy and antibody treatments will be continued after surgery, to ensure there are no cancerous cells left behind. There is a chance that these treatments may not work, the cancer may develop resistance, or the cancer may come back. In these cases, alternative antibody-drug conjugates are used.

What motivates Zachary's research?

"As tumour-targeting antibodies are barely used for other solid tumours, I want to understand the underlying therapeutic mechanisms for this treatment to see if it could be extended to other cancers and improved upon in breast cancer," explains Zachary. "And I want to understand why some antibody-drug conjugates work better than others." Additionally, Zachary aims to explore the potential of a HER2 vaccine, which would stimulate HER2-specific immunity in a similar way to how vaccines are used for viruses (such as COVID-19). This is more difficult, however, as HER2 is also present in healthy cells, and vaccine-generated immunity may not be tumour-specific.

Zachary's research also aims to fill gaps in our knowledge of tumour immunity. Studies on how HER2 monoclonal antibodies work have been started but are far from complete. These antibodies were originally thought to function by stimulating one type of immune cell (the natural killer cells) or blocking tumour growth signalling, rather than triggering the whole immune system. It has now been found that there are other, more important cells (e.g., macrophages) that can be credited for the response – and researchers are continually learning more about how they stimulate immunity.

What experiments and trials have been done so far?

Zachary's research has reached the *in vivo* experiment stage. For this, HER2+ breast cancer cells are injected into mice. Once the cancer has developed, monoclonal antibodies or antibody-drug conjugates are injected to provide insights into how the anti-tumour response is caused. Zachary and his team have also been able to knock out certain genes and proteins and even deplete cell types to study the treatment function and what is needed for the anti-tumour response.

Zachary's antibody research has not yet reached clinical trials, but he has conducted early-stage HER2 vaccine trials, with under 50 participants, looking at whether HER2-specific antibodies and white blood cell responses are generated from the injection of the recombinant HER2 expressing viruses.

How can the results be used in real life?

So far, Zachary's research has shown that HER2 vaccines do trigger specific immune responses and can also stop the immune system from tolerating HER2. Whilst this response was not found in all patients, those with the response had better outcomes than those without. Critically, the HER2 vaccines were demonstrated to be very safe and were unable to provoke obvious autoimmunity, thus suggesting their ability to elicit cancer targeting immune responses.

Uncovering how these anti-tumour responses work for monoclonal antibodies, antibody-drug conjugates and vaccines will enable current treatments to be improved upon. Zachary's research also opens the opportunity to use these types of treatments on other cancers. "It is likely this would be on tumours with genes similar to HER2," he explains.

What are the next steps?

There is plenty of understanding of how the antibodies trigger the innate immune system (including previously mentioned macrophages and natural killer cells), but the effect on the adaptive immune system is yet to be seen. The HER2 vaccine also needs more research, as responses need to be improved since tumour areas are usually immune suppressive. Zachary explains, "To understand if the same principles would hold in cancers in different tissue microenvironments, we need to test some of our findings from HER2 monoclonal antibodies and antibody-drug conjugates against other targets in different cancers."

About *immunology*

Immunology is a specialist area of biomedical science, focusing on research involving the immune system. It focuses on how the body can protect itself from infectious diseases caused by microorganisms. These could be bacteria, viruses, fungi or parasitic organisms, which are all capable of causing intense bodily harm. Immunology can be applied to many different areas, such as vaccines, cancer, allergy and autoimmunity, as well as some that you may not associate with immunology, such as neurodegenerative diseases like Alzheimer's disease.

Many people have heard of Edward Jenner, the 19th century scientist who discovered that if someone had previously had cowpox, they were protected against smallpox, which was fatal. At the time, he was not aware of microorganisms, which were discovered the following century, or what was going on within the body to cause this protection. However, Jenner's discovery is thought to be the origin of immunology. His research led to many other scientists using the same principle to create other vaccines against infections, such as cholera and rabies. It was in 1890 when the key component of antibodies was found. This discovery allowed immunology research to become what it is today, and researchers like Zachary are developing new understanding in this vital field all the time.

Explore careers in *immunology*

Zachary says, "I encourage you to read and reach out for opportunities in science. Before college, there are programmes to become involved with; many laboratories have undergraduate students who are involved in their research programmes. Generally, for admission to PhD and some medical programmes, this type of work and experience is a prerequisite."

As an immunologist, you could conduct research at a university, for a charity or private/public health sector. This could be in specialist areas including HIV and organ transplantation. You could teach at a university and educate doctors in training or work in clinical immunology to investigate patient immune systems and the causes of any problems.

Duke University has many science-related outreach projects as part of its Center for Pathway Programs: **sites.duke.edu/centerforpathwayprograms**

Duke University's Center for Applied Therapeutics provides opportunities for talented high school students to work in their laboratories: **www.dukecat.com**

In the UK, The British Society for Immunology offers internships: **www.immunology.org/careers/bsi-careers-support/bsi-internship-scheme**

Pathway from school to *immunology*

Specific academic requirements for studying immunology at university vary between countries, but biology is a key subject to study.

To pursue clinical immunology (and to work with patients) in the US:

- Earn your bachelor's degree, preferably in a relevant subject (e.g., biology)
- Complete the Graduate Record Examinations test and attend graduate school or the Medical College Admission test and attend medical school
- Complete the US medical licensing examination
- Participate in a residency programme and an immunology fellowship
- Certify under the American Board of Allergy and Immunology to practise.

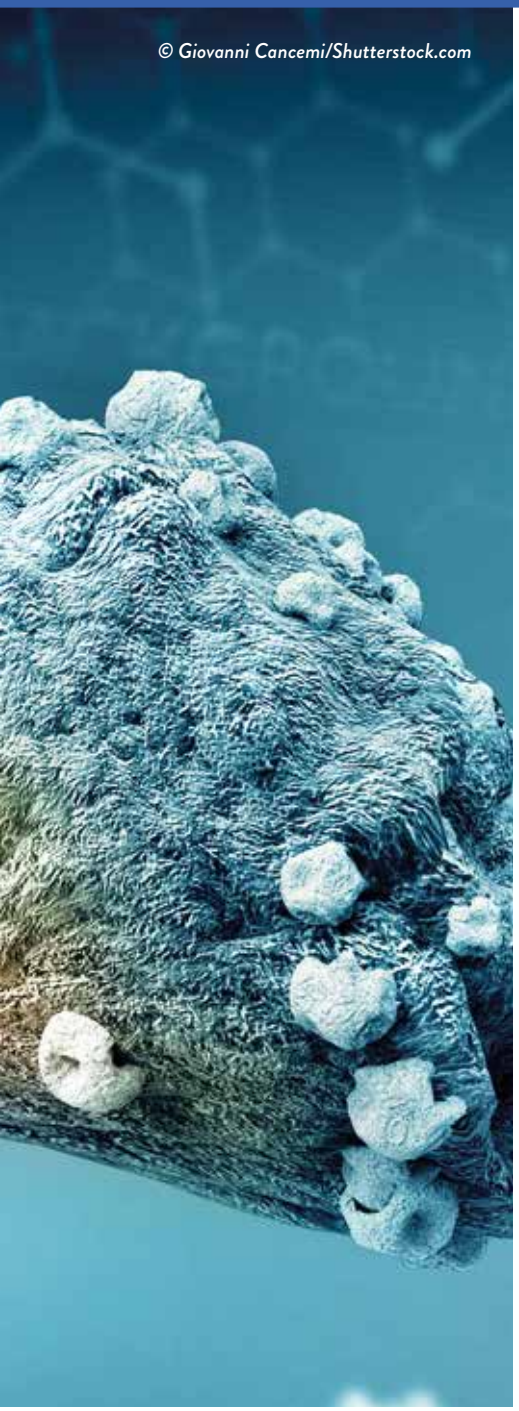
Zachary adds, "To follow more of a research-orientated path, you could get your PhD during graduate school and then do post-doctoral fellowships."

See The American Association of Immunologists for more information: **www.aai.org/Careers/Graduate-Programs**

In the UK:

- Gain high grades in your GCSEs
- Earn three A-levels in chemistry, biology and, possibly, maths or physics
- Complete medical school
- Complete the foundation programme and apply for speciality training
- Complete a PhD to become more specialised.

Find out more from the UK's National Health Service: **www.healthcareers.nhs.uk/explore-roles/healthcare-science/roles-healthcare-science/life-sciences/clinical-immunology**



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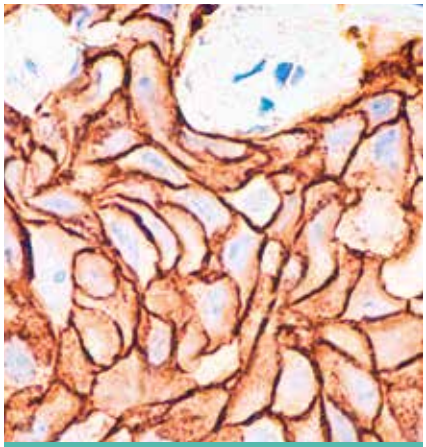

Immunohistochemistry for HER2 shows positive cell membrane staining in this poorly differentiated (grade 3) infiltrating ductal carcinoma.
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Q&A
Meet *Zachary*

What was your pathway to becoming an immunologist?

I was always interested in biology and evolution, so I decided to study genetics in graduate school. There, I joined a gene therapy lab and was fascinated by the biology and potential of viruses. I became engrossed in understanding how innate immune responses were triggered by viruses, which led to a broad interest in using viral vectors for vaccines. At the end of my time at graduate school, my father was diagnosed with metastatic prostate cancer, spurring my interest in cancer immunotherapy and the use of different approaches to stimulate anti-tumour immunity.

What moments have shaped your career?

There have been too many formative experiences to summarise, but eureka moments are the part of the job that keeps you going. Sometimes they are not obvious or are only seen in hindsight. For instance, during graduate school, I was trying to figure out why a specific virus was eliciting immune responses, so I experimented on mice with a specific gene knocked out. Almost all responses went away in the knock-out mice, except in one mouse. I was disheartened, thinking it invalidated the importance of this gene. However, my advisor thought I was crazy and that the results were great. I then went back and re-evaluated the mouse, finding that it had been miscategorised due to a genotyping error. Thus, I found that this gene did dramatically alter immunity and that you really have to pay attention to larger patterns in biology and make sure to confirm everything.

What is challenging and rewarding in your career?

Science is a unique pursuit in its constantly challenging nature. I think to be effective, you must get used to failure being common. You need to find different ways to approach a problem, often again and again and again from different angles, to figure out what is happening.

The rewarding parts of my career are the discoveries we've made and the papers we've published, which are joint ventures with lots of other scientists. Additionally, I think training other scientists and collaborating in a larger community are rewarding experiences. That said, I hope that my proudest moments are yet to come!

What are your aims for the future?

To continue making progress in understanding cancer immunology and contribute to better therapies for patients. A great thing about science is that you can get a feeling of accomplishment and satisfaction by contributing to the knowledge base and creating tools and techniques that will facilitate research for future generations.

Zachary's *top tips*

1. Do lots of background reading – it'll serve you well in the long run.
2. Don't be afraid to test basic assumptions.
3. Things are not as simple as you may hope or as might be portrayed.
4. Don't get discouraged if things don't work out quickly!

How the latest tech is unveiling the brain's complex functionality

Understanding how our brains work in health and disease is hugely challenging, not least because all interactions have to be performed on a delicate, complex, actively working brain. Magnetoencephalography (MEG) is a powerful non-invasive technique that detects brain function by measuring the magnetic fields produced by the brain's electrical activity. With this technique, it is possible to study and diagnose many brain functions and mental health disorders. **Dr Orang Alem, Dr Svenja Knappe, Dr Jeramy Hughes** and their team at **FieldLine Medical** have developed a novel and wearable MEG device using their quantum sensor technology.

Dr Orang Alem

FieldLine MEDICAL

Co-founder and CEO, FieldLine Medical, USA

PROFILE

Fields of research
Atomic physics, biomedical engineering

Research project
Developing a wearable magnetoencephalography (MEG) device, the FieldLine HEDscan system

Funders
US National Institutes of Health (NIH), Department of Defense (DoD)

Talk like an ...

applied physicist

Cryogenic — related to the production of very low temperatures

Magnetoencephalography (MEG) — a technique to measure brain activity by recording the magnetic fields produced by the electrical activity of neurons

Neuron — a nerve cell that uses electrical currents to send messages to, from and within the brain

Optical pumping — a process that uses light to raise ('pump') electrons to a higher energy level

Optically pumped magnetometer (OPM) — an instrument to measure magnetic fields by manipulating and observing atoms as they interact with this magnetic field

Quantum mechanics — the science that describes how matter and light behave at the atomic and subatomic scale

The human brain is the most complex thing in the known universe, and understanding how it functions has never been easy. Scientists and medical professionals need methods and tools to study the brain so they can understand what happens when things go wrong. The brain's intricate mesh of electrically active neurons is responsible for how we perceive and act in the world. While powerful technologies to study brain activity do exist, they each have critical limitations, limited applicabilities and high cost. Dr Orang Alem, co-founder and CEO of FieldLine Medical, and his colleagues have applied their physics knowledge to develop a solution to these challenges.

Magnetoencephalography

"Magnetoencephalography (MEG) is a non-invasive technique that detects and records brain function," explains Orang. "It provides information on the nature and location of neural activity." MEG technology uses an array of magnetic sensors place around the surface of the head to detect the magnetic fields produced by the electrical activity of neurons. By recording these magnetic fields and observing how they change over time, it is possible to locate and build functional networks of human brain processes.

"MEG is used to fundamentally understand the brain and how it functions," says Orang. "It helps scientists investigate everything from consciousness to memory, decision-making to learning." As MEG can be used to observe traits of just about every function of the brain, it is a useful tool for detecting when any of these functions are not working correctly. "This means MEG

MEG is used to diagnose and monitor:

- Epilepsy
- Dementia
- Post traumatic stress disorder
- Autism spectrum disorder
- Parkinson's disease
- Schizophrenia
- Traumatic brain injury

The wearable magnetoencephalography device developed by Orang and his team © FieldLine Medical

can assist in diagnosing and monitoring a wide range of brain conditions, such as epilepsy, dementia, depression and traumatic brain injury."

MEG drawbacks

MEG technology is extraordinarily powerful, but current MEG devices have several practical drawbacks. "Available MEG devices use cryogenic sensors that must be cooled to temperatures of four degrees Kelvin (-269 °C) with liquid helium," says Orang. "Not only is liquid helium very expensive (it costs hundreds of thousands of dollars a year just to cool the sensors), but the sensors must be heavily insulated to maintain these ultra-low temperatures and to protect the person's head." This insulation increases the distance between the sensor and head. Given that the magnetic fields generated by the brain are very weak and that the strength of a magnetic field dramatically decreases with distance from the source, it is important for the sensors to be as close to the brain as possible to detect the magnetic signals.

Cryogenic sensors are also very bulky and not easily adaptable, meaning the cavity in the machine where the patient places their head cannot be adjusted. "Cryogenic MEG devices are designed to fit the largest heads, so anyone with a smaller head is further from the sensors and detection of their brain's magnetic fields will be poor," says Orang. "It also means the patient must sit very still during a scan, which is not always possible for infants, children and some adults." At about the size of a large fridge, cryogenic MEG devices need a large room to operate, and these rooms must be magnetically shielded

> ***"MEG is used to fundamentally understand the brain."***

to prevent interference from outside magnetic signals, such as nearby doors, elevators and passing traffic. "The shielding is very expensive," says Orang. "It is also very heavy, meaning special facility reinforcement is necessary, which increases the cost again."

A new technology

The FieldLine team realised their quantum sensor technology could overcome these limitations, so they used it to create a viable alternative. They have developed a wearable MEG device, the FieldLine HEDscan system, which requires no supercooling at all, as it uses a very different sort of sensor. "In our system, the brain's magnetic fields are measured using an optically pumped magnetometer (OPM)," says Orang. "It uses atoms and the principles of quantum mechanics to detect magnetic fields." Atoms in the sensor are 'optically pumped' to enter a specific quantum energy state that makes them highly sensitive to magnetic fields. The presence of magnetic fields (such as from the brain) will affect these spins in specific ways, depending on their strength and direction, and this change in spin is detected by the sensor. "OPMs are one of the most sensitive methods for detecting very weak magnetic fields," says Orang. "Outside of medicine, there are many further uses for OPMs, including in magnetic surveying, navigation, materials testing, and geophysics and space applications."

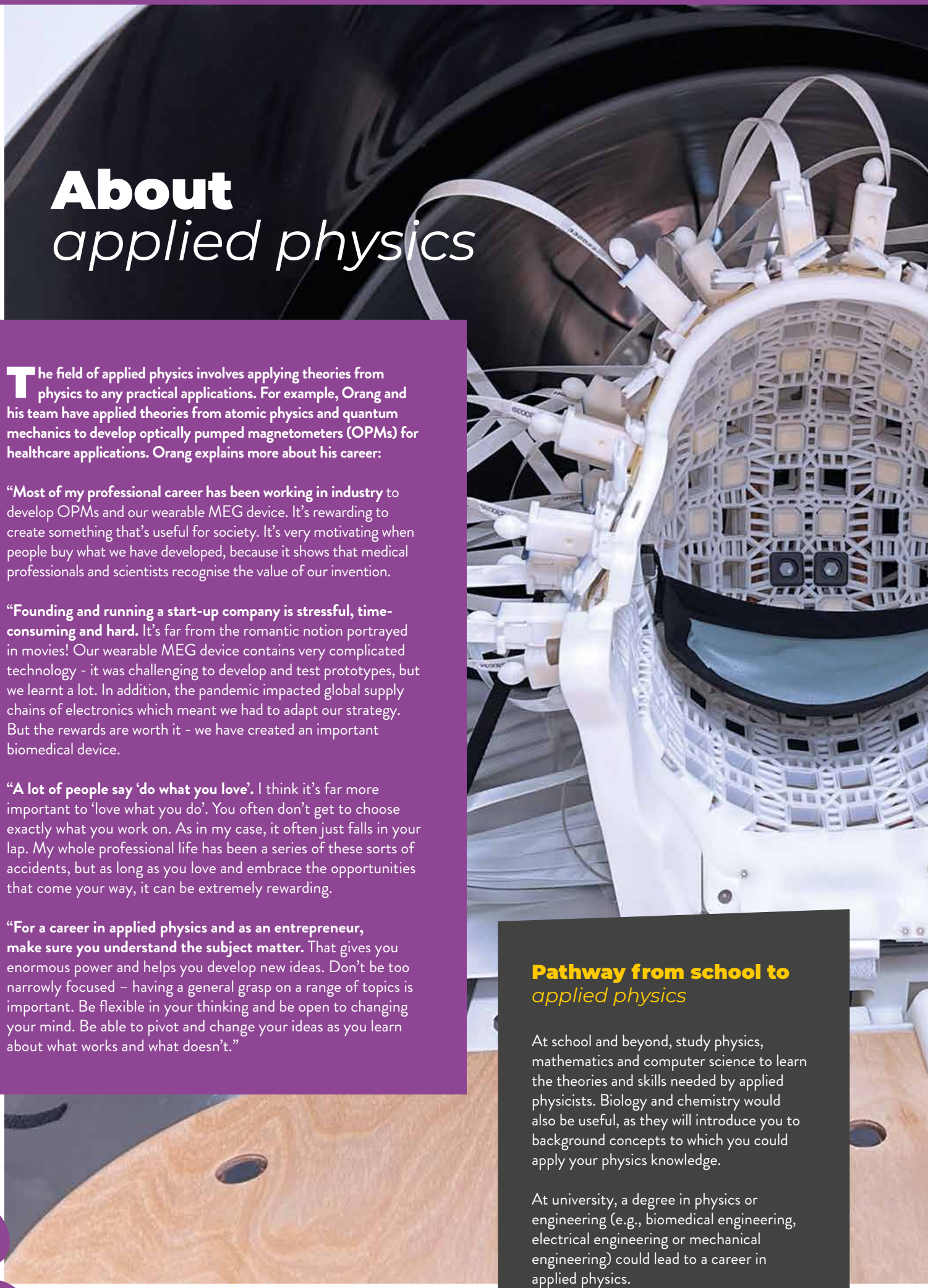
Accessibility, adaptability, affordability

The FieldLine HEDscan overcomes the issues of standard cryogenic MEG systems. "Our system involves a helmet (the size and shape of a motorcycle helmet) that contains an array of over 100 OPMs," says Orang. "They can be positioned so that all OPMs are in contact with the head, meaning the device functions equally well for any size or shape of head." Because it fits onto the head, the device moves with the person, so it is not an issue if they cannot stay still during the scan. And because it is small, it can operate in a small room, so the costs of magnetic shielding are much lower and infrastructure modifications are not required.

Cryogenic MEG systems cost several million dollars, but the FieldLine HEDscan wearable MEG device costs just a fraction of this. "As our system works without cryogenic sensors, there's no need for supercooling," says Orang. "In fact, our entire system plugs into a single electrical outlet, and consumes a quantity of electricity equivalent to a toaster!"

With this new invention, Orang and the FieldLine team have dramatically increased the practicality, accessibility and affordability of MEG technology, opening the door to improvements in the diagnosis and monitoring of brain conditions.

About *applied physics*



The field of applied physics involves applying theories from physics to any practical applications. For example, Orang and his team have applied theories from atomic physics and quantum mechanics to develop optically pumped magnetometers (OPMs) for healthcare applications. Orang explains more about his career:

"Most of my professional career has been working in industry to develop OPMs and our wearable MEG device. It's rewarding to create something that's useful for society. It's very motivating when people buy what we have developed, because it shows that medical professionals and scientists recognise the value of our invention.

"Founding and running a start-up company is stressful, time-consuming and hard. It's far from the romantic notion portrayed in movies! Our wearable MEG device contains very complicated technology - it was challenging to develop and test prototypes, but we learnt a lot. In addition, the pandemic impacted global supply chains of electronics which meant we had to adapt our strategy. But the rewards are worth it - we have created an important biomedical device.

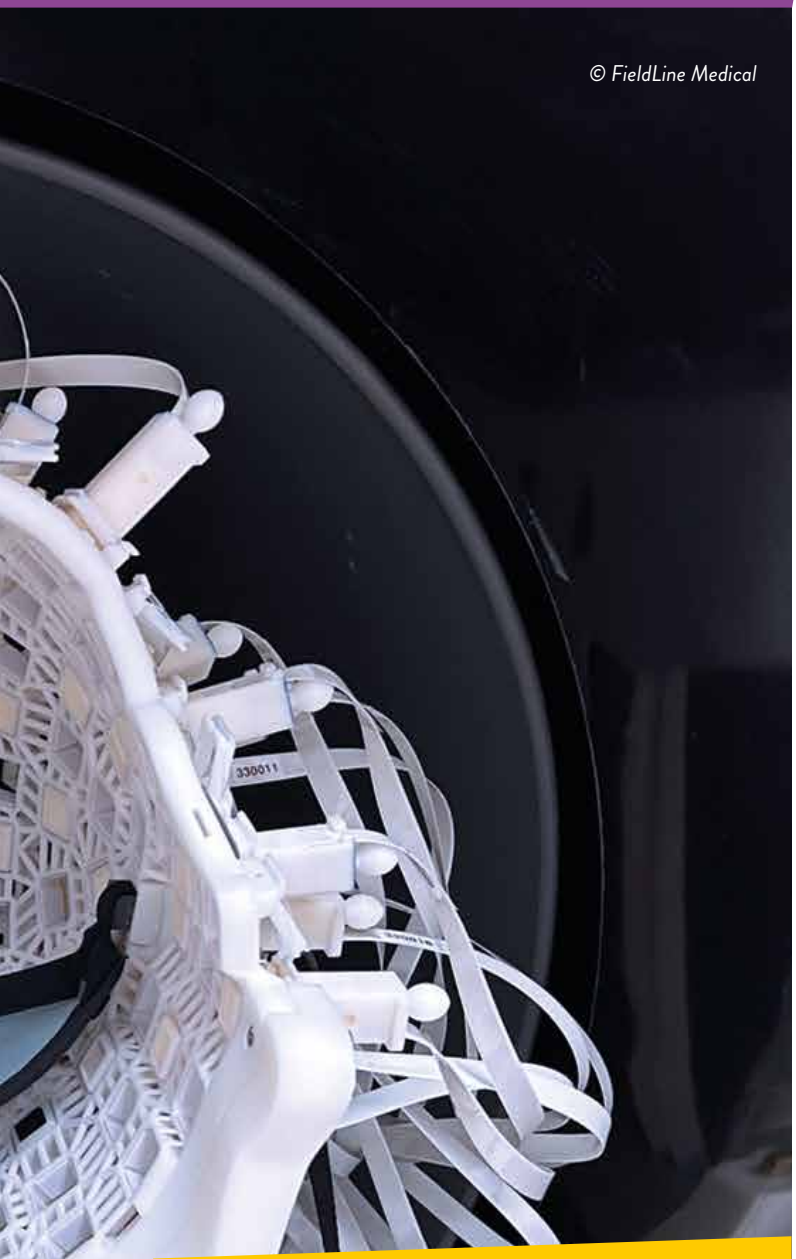
"A lot of people say 'do what you love'. I think it's far more important to 'love what you do'. You often don't get to choose exactly what you work on. As in my case, it often just falls in your lap. My whole professional life has been a series of these sorts of accidents, but as long as you love and embrace the opportunities that come your way, it can be extremely rewarding.

"For a career in applied physics and as an entrepreneur, make sure you understand the subject matter. That gives you enormous power and helps you develop new ideas. Don't be too narrowly focused – having a general grasp on a range of topics is important. Be flexible in your thinking and be open to changing your mind. Be able to pivot and change your ideas as you learn about what works and what doesn't."

Pathway from school to *applied physics*

At school and beyond, study physics, mathematics and computer science to learn the theories and skills needed by applied physicists. Biology and chemistry would also be useful, as they will introduce you to background concepts to which you could apply your physics knowledge.

At university, a degree in physics or engineering (e.g., biomedical engineering, electrical engineering or mechanical engineering) could lead to a career in applied physics.



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Explore careers in *applied physics*

With a career in applied physics, you could find yourself working in academia or industry. Academic applied physicists investigate the physics theories and scientific principles that can be applied to practical situations, while industrial applied physicists, such as Orang, apply these theories to develop new technologies for commercial use.

Gain work experience in different sectors of physics to learn about the day-to-day work of different roles. Reach out to universities and engineering companies near you to see if they offer opportunities to get involved with their work.

The American Physical Society provides information about different careers in physics: **www.aps.org/careers**

The International Union of Pure and Applied Physics promotes physics education and outreach: **www.iupap.org/strategic-plan/outreach**

Meet *Orang*

I was always that kid who wanted to know 'why?'. I always wanted to understand the underlying principles and how things worked. At school, I loved and excelled at math and science. I also loved looking at the night sky. It filled me with wonder and so many questions. From a young age, I knew I wanted to be a scientist.

However, with my Iranian background, I felt the cultural pressure to become a medical doctor. So, I went to university to study biology and medicine, but I soon realised that I really didn't want to be a physician. I enjoyed studying biology, but I wanted to understand the underlying reasons behind what was happening in biology, so I started taking chemistry classes to find out. Then I wanted to understand the underlying reasons behind chemical processes, which led me to physics.

I really enjoyed studying physics because understanding the fundamental basics of science gave me the foundations to build upon. I realised that an understanding of physics and the skills one learns as an experimental physicist can lead to many careers outside of physics or academia. These skills and knowledge help me to solve many problems and develop practical applications.

For my graduate research in atomic physics, I studied and developed different types of OPMs. I started my professional career in industry developing commercial OPM sensors for different applications. Along with my two colleagues, Dr Jeramy Hughes and Dr Svenja Knappe, we decided that we wanted to take the OPM technology that we had developed all the way to build a medical device. This motivated us to found our company, FieldLine Medical, and develop our wearable MEG device. We wanted to build something that would be useful for neuroscience and mental health diagnosis, and which could help millions of people.

Orang's *top tips*

1. As a scientist, it is important to have curiosity and a desire to understand why and how things happen.

2. As an entrepreneur, it is important that you can take calculated risks and not be deterred by naysayers.

3. In both roles, teamwork is key. You need to be able to work with other people to turn your visions into reality.

Transforming agriculture with solution-driven science

In recent years, the agricultural industry has faced unprecedented challenges due to emerging pests and diseases threatening crop production worldwide. **Dr Robert Shatters**, a research scientist at the **US Horticultural Research Laboratory**, discusses the transformative potential of solution-driven science in addressing agricultural crises and pushing the industry towards a more resilient and sustainable future.

Dr Robert Shatters

US Horticultural Research Laboratory,
US Department of Agriculture, USA

PROFILE

Field of research
Molecular and cellular genetics

Research project
Restructuring the academic model to deliver solutions to emerging pest and disease issues in crop production

Funders
US Department of Agriculture (USDA), National Institute of Food and Agriculture (NIFA)

Talk like a ...

research scientist

Biosecurity toolbox — a set of guidelines and tools to prevent and respond to threats in agriculture

Huanglongbing (HLB) — a bacterial disease (also known as citrus greening disease or CGD) affecting citrus trees, leading to significant damage and eventual tree death

Phloem — the tissue in plants that transports sugars and other organic compounds produced by photosynthesis from the leaves to other parts of the plant

Symbiont™ platform — a method to deliver therapeutic molecules to citrus trees to combat HLB

Vascular system — the system of vessels (such as xylem and phloem) in plants that transport water, nutrients and other substances throughout the plant

Vector — an organism, often an insect or other animal, that transmits pathogens from one host to another

In today's agricultural industry, there is a pressing need to rethink our approach to scientific inquiry. As challenges such as emerging pests and diseases threaten crop yields worldwide, it becomes increasingly evident that traditional research models fall short of delivering timely and effective solutions. At the US Horticultural Research Laboratory, Dr Robert Shatters emphasises the urgent need to re-evaluate and reshape the existing ways of conducting science. His insights – along with those of the many scientists he collaborates with – highlight the importance of adopting innovative and collaborative approaches to address the complex and multifaceted challenges confronting the agricultural sector today.

The challenges

One challenge faced by the agricultural community currently is huanglongbing (HLB), sometimes called citrus greening disease – an example of the dire consequences that can arise without proactive and solution-oriented scientific approaches. HLB is a bacterial disease transmitted by insects that affects citrus trees (such as orange, grapefruit and lemon). "The bacterium lives in the plant's vascular system and is transmitted from plant to plant solely by the Asian citrus psyllid, a small insect that feeds on the vascular system, much like a mosquito feeding on our vascular system," explains

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Robert. "It starts to damage the plant's vascular system and blocks movement of food from the leaves to the roots." This gradual damage weakens the tree, causing it to eventually die. As a result, it is very difficult for farmers to maintain healthy citrus trees and ensure a reliable fruit supply for consumers.

The insect responsible for spreading the bacteria causing HLB was first found in Florida in 1998. It was not until 2005 that people noticed the disease affecting citrus trees in the state. Unfortunately, when the tree becomes infected with the bacteria, it takes a long time for any signs of sickness to appear. "There is a long latency period of around two years, when the bacterium is dividing and moving systemically in the plant, but there are no visible symptoms of disease," says Robert. "Psyllids moved the bacterium all over Florida citrus crops for years before the disease was detected. When the disease *was* finally detected, it was too late to contain and eradicate it." Intense US research on this disease did not start until after it was discovered in 2005, even though it was a major threat to citrus trees worldwide for a long time. This delay meant that scientists had to start from scratch, conducting basic research to understand the disease better. The funding for this research followed the typical academic model, with lots of small research projects gathering basic information.

Florida's citrus industry is an example of the consequences of delayed action

> **"... traditional research models fall short of delivering timely and effective solutions."**

in the face of agricultural crises. More specifically, Florida's citrus production dropped by nearly 90% from 233 million boxes in 2000 to just 16 million boxes in 2023 – this is the collapse of a major horticultural crop. The citrus processing plants, packinghouses, and all associated industries (food, irrigation, equipment, harvesting) have also been impacted. While the disease is also present in California and Texas, its spread there has been slower. However, there are concerns within the industry that these states could suffer significant impacts in the future.

Current strategies

Efforts to fight HLB vary across states in the US. "In Florida, where the disease is widespread, they are trying different things like looking for more supportive rootstocks, using nutritional supplements and therapeutics to keep infected trees healthy, and controlling the Asian citrus psyllid vector," says Robert. "Meanwhile in California, the focus is on stopping the disease from spreading." This involves restricting the population of Asian citrus psyllids, destroying infected trees, and teaching people in the industry how to prevent it. Despite spending a lot of money (>$1.4 billion) on these efforts, the current approaches have not worked. "Intensive vector controlling activities did not reduce the spread in Florida, and nutritional treatments are costly, with average production costs increasing from $880 to $1875 per acre between 2004 and 2018 in the state," explains Robert. "Recently, many growers have started to inject trees with therapeutic molecules (i.e., oxytetracycline)." While this method has shown promise in improving tree health, it is not sustainable in the long term, and researchers need to find other ways to treat the disease so that the bacteria do not become resistant to current treatment options. These challenges show the complexity of combatting diseases such as HLB and the need for continued research and innovation to develop effective and sustainable solutions.


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Huanglongbing (HLB) makes it difficult for farmers to maintain healthy citrus trees.

Global *agriculture*

The example of huanglongbing (HLB) is a warning sign for other agricultural problems. As trade moves more goods around the world and climate change expands the areas where plant diseases and the insects that carry them can thrive, similar challenges affecting other crops are expected.

Dr Randy Niedz

Research Geneticist, US Department of Agriculture, US Horticultural Research Laboratory

Dr Randy Niedz explains, "The same dynamics are almost certainly present in other systems. Coffee and cocoa crops have serious diseases of their own which will have the same effect: increased cost of production and higher costs to the consumer."

There are many known crop diseases currently in isolated areas that are being watched for their potential movement into major commodity production areas. Robert explains, "This is exacerbated by the global desire to move away from chemical pesticides that can be very effective but often have a negative impact on the environment." Without alternative biosecurity tools, these agricultural problems could become worse, putting global food production at risk. "If we see this as a war, we can then see the need to have multi-layered security that includes monitoring, surveillance, quarantine, eradication, and management practices," says Robert. "These practices need to be integrated and conducted on a global scale through international collaborations."
A report by the United Nations Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services highlights the importance of the situation, revealing that invasive species cost the world around $423 billion every year.

A call for a coordinated effort

To better address agricultural challenges, we need to rethink how research is conducted. "The 'academic model' for research is important, allowing diverse areas of research based on a broad spectrum of hypotheses to be conducted," says Robert. "The 'cast a broad net' concept helps in collecting diverse data on a specific topic, but also takes time, and often creates redundancies and other issues associated with a lack of focus." In the case of HLB, there was a crucial need for problem-solving research, but much of the funding was directed towards basic science. Research needs to transition towards coordinated, multidisciplinary projects where teams work together towards common goals, rather than individual projects operating independently.

At a bigger scale, dealing with agricultural challenges requires international cooperation. "Invasive species do not respect borders," says Robert. "Understanding the dynamics of the global situation with respect to emerging crop pest, pathogen and weed problems will allow a global targeting of solution-driven resources. This will address emerging issues before they spread to major agricultural production areas, and at the same time, create solutions to all sectors of the globe with respect to food security." This approach ensures food security for all and promotes worldwide economic well-being.

Moving away from the academic model

Moving to a more practical approach is essential for addressing agricultural challenges effectively. "It means defining the problem and what the relevant measures are – and involving all the related experts (including growers) in the experimental design planning," says Randy. "This more efficient approach means identifying treatments that have large effects (and that growers can use) and then using the academic model to understand how that treatment is working."

Dr Rodney Cooper

Research Leader, US Department of Agriculture

Dr Rodney Cooper highlights the potential for specific tools developed for one crop to be applied to different crops facing similar challenges. A great example of this adaptability is presented in the ongoing battle against cherry X-disease – an epidemic that has caused devastating economic losses exceeding $150 million in the cherry industry in the Pacific Northwest in recent years. "Cherry X-disease is caused by a plant pathogen called *Phytoplasma pruni* that is transmitted to plants by several leafhopper vectors that feed primarily on broadleaf weeds," explains Rodney. "Like HLB, there are no cures for cherry X-disease, so growers must rely upon the use of insecticides to reduce vector populations." With symptoms appearing approximately three years after initial infection, the disease spreads through orchards unnoticed. Farmers often have to remove whole infected orchards to stop it from spreading further. New fruit trees cannot be planted in those areas for another six years because there is still a risk of the new trees getting infected from old roots.

Drawing parallels with the early years of combatting HLB in Florida, researchers in the Pacific Northwest face a pressing need to develop practical solutions for cherry growers dealing with the X-disease epidemic. "Luckily, citrus greening research provides the researchers with research directions that will have the greatest return on investment," says Rodney. "Specific tools like 'Symbiont™' and direct infusion of antibiotics may be directly adaptable for use against cherry X-disease." Using the groundwork laid by HLB research, scientists can accelerate the adaptation and delivery of practical solutions to mitigate the impact of X-disease on cherry cultivation. (Learn more about Symbiont™ technology on page 74.)

The need for a biosecurity toolbox

Factors such as the increasing human population and the growing desire to limit reliance on synthetic pesticides highlight the need for innovative solutions provided by a biosecurity toolkit. Moreover, the increased global movement of agricultural goods increases the risk of introducing invasive species into new ecosystems, which makes the development of biologically-based alternatives necessary.

Human activities, particularly those related to global trade, contribute significantly to the introduction, and spread, of invasive species. "Insects, plants and pathogens often enter the US on shipping containers at major ports," says Rodney. "The vast majority of these introductions are intercepted or fail to establish, but the minority that become established can cause enormous economic damage." Invasive species can also exploit other pathways for introduction, including transportation on trains, trucks, and even through travellers carrying contaminated firewood.

The risks associated with invasive species are not always apparent at first glance. For example, the spread of an invasive plant species may accidentally facilitate the expansion of native insects into new territories, where they can emerge as major pests. At the same time, the introduction of a non-native insect could potentially transmit unknown pathogens from weeds to crops, exacerbating agricultural challenges. "A biosecurity toolbox provides a set of guidelines for solution-driven science and highly adaptable tools that can be deployed rapidly to prevent establishment and spread of invasive species," explains Rodney. "It breaks the cycle of using huge amounts of funds to pool information and focuses research efforts on rapid responses to new problems."

Climate change adds to the severity of the situation by changing the geographical range in which invasive species can survive. "Invasive species are often less susceptible to climate change than most endemic native species," says Rodney. "If the temperature increases in an area, pests, pathogens and weeds that could not survive in that region before, can now thrive." This greater adaptability to changing climates amplifies their competitive advantage, allowing them to flourish in diverse environments. This can disrupt existing pest management practices and make the challenges faced by agricultural systems worse.

The concept of a biosecurity toolkit addresses the constant threats from invasive pests and pathogens that can harm various agricultural and natural systems. A biosecurity toolkit offers a clear and structured plan to identify critical knowledge gaps quickly and provide adaptable, sustainable, and cost-effective tools for responding to these challenges. "The academic model tends to produce competing research interests and mountains of data without a clear direction for using that knowledge to develop practical solutions," says Rodney. "Solution-driven science puts an emphasis not only on gathering key information but also on moving 'pie-in-the-sky' ideas out of laboratories and into the field." By using existing technologies and adapting them to new contexts, the biosecurity toolkit facilitates the rapid development and implementation of solutions to fight emerging biosecurity threats.

Multidisciplinary *team building*

Dr Lorenzo Rossi

Root Biologist, University of Florida

Dr Laura Fleites

Project Leader, Agrosource Inc.

Dr James Thomson

Research Geneticist, US Department of Agriculture

In agricultural research, a wide array of disciplines converge to tackle complex challenges. Dr Lorenzo Rossi emphasises the importance of disciplines such as plant biology, chemistry, botany, horticultural sciences, tree physiology, molecular and cellular biology, plant pathology, agricultural engineering, plant breeding, and postharvest fruit physiology. This multidisciplinary approach is vital as researchers' combined efforts form the backbone of comprehensive problem-solving strategies.

Knowledge produced by the academic model is very important for understanding the complexities of agricultural challenges. Researchers need to comprehend the interactions between pathogens, plants and vectors, as well as the molecular pathways that facilitate invasion. "However, that knowledge is useful only if multidisciplinary teams communicate and work to mould that knowledge into workable solutions," says Rodney. "What use is a new molecular tool to eliminate a pathogen from trees without an engineer to design a delivery mechanism, or a horticulturalist to advise on solutions that can be integrated in current production systems?"

Dr Laura Fleites highlights the need to understand each element to develop and optimise a system. She explains, "It would be ill-advised to modify one element without being able to predict and measure the effect of the modification on other elements in the system." A collaborative approach ensures that research findings are transformed into actionable strategies that address real-world agricultural issues effectively.

Empowering individuals

A team approach can empower individuals by using diverse expertise and perspectives, allowing each member to contribute unique insights and skills. The recognition and appreciation individuals receive for their contributions promotes a sense of fulfilment and encourages problem-solving from multiple angles, cultivating personal and professional growth. Laura explains, "Individuals working on the project can find their niche and learn aspects of the science that resonate with them. We have team members with varied backgrounds and educational levels, and we solicit feedback from each other regularly. Everyone is encouraged to dig deeper into the subject areas that they find of particular interest."

Empowered individuals make for a more successful team. "Individuals can shine as their effort is appreciated," says Dr James (Jim) Thomson. "I had nothing to do with the original idea to create the Symbiont™ for drug delivery, nor did I come up with the genes that will eventually produce the disease resistance, but I did contribute to the assembly and delivery of those genes for field test, looking for the 'big effect', and I'm proud that I contributed to a potential solution. Everybody, from the farmers that allow us to use their fields (giving up trees that could be used for citrus production) to the people getting on their knees in the mud to test Symbiont™ in the field should all be praised for their efforts." This inclusive approach acknowledges the importance of every individual's contribution, emphasising that success is a result of collaborative effort rather than individual achievements alone. "This project empowers individuals to make meaningful contributions towards addressing complex challenges such as combatting HLB, while also fostering a sense of collective achievement and impact," says Lorenzo. Through collaborative efforts, significant successes have been achieved that would not have been possible otherwise.

Jim highlights the importance of group effort in accomplishing various milestones, including the development of the Symbiont™ concept (see page 74), the expression of disease resistant genes, and the implementation of the inoculation process for field trials. Similarly, Lorenzo emphasises the ground-breaking achievements made in addressing HLB through interdisciplinary collaboration. "By pooling our expertise, we have made significant strides in developing innovative solutions for combatting HLB, such as conducting large-scale field trials with numerous molecules and collaborating with growers across Florida, as well as partners from other states," says Lorenzo.

Changing the way scientists think

The new approach to collaborative and interdisciplinary research is revolutionising the way scientists think about their work and its impact on society and the environment. Traditionally, scientists have been trained to focus on individual research projects aimed at furthering their careers through publications and grants. However, the emergence of existential challenges, like environmental degradation and biodiversity loss, demands a shift towards collective problem-solving. "New scientists need to learn how to balance their personal portfolio of research to contain two types of research: becoming an expert in their field by applying the classic academic model of conducting research and then plugging their knowledge into a collective multi- and transdisciplinary approach to create solutions to existential problems," explains Robert. With the rapid pace of technological advancement leading to a doubling of knowledge approximately every 12 months, scientists must adapt to effectively apply their expertise to real-world problems.

"Scientists often think in terms of self. Not necessary out of selfishness but out of necessity," says Jim. From securing a job to applying for funding, scientists face many day-to-day pressures. A collaborative team approach allows scientists to move beyond the narrow focus of personal achievements and work towards shared goals. This shift in mindset encourages cooperation, knowledge sharing and the recognition of individual contributions within the team. Group publications become a testament to collective efforts, showcasing not only scientific expertise but also the ability to collaborate effectively and prioritise societal needs over personal gain. In fields like agriculture, where challenges like HLB and cherry-X disease threaten livelihoods, the focus must shift from individual efforts to delivering practical solutions to farmers in need.

However, breaking through the traditional mindset of individual achievement has its challenges, often manifesting as 'the wall', where researchers struggle to translate their expertise into tangible solutions. "As researchers analyse their results, they find that they cannot yet use the knowledge gained to deliver a solution to the problem being studied," says Robert. "As a result, they go back and design other experiments still within the boundaries of their area of expertise because they do not know how to advance beyond that limit of knowledge." Overcoming this barrier requires scientists to step out of their comfort zones and engage with diverse disciplines to move their gained knowledge into a deliverable solution. "To me, 'the wall' is the divide between concept and execution," says Laura. "Ideas are great, but they're nothing if you do not advance them in tangible ways. Doing this requires grit and determination."

Dr Tom D'Elia

Biology Professor, Indian River State College, Fort Pierce, Florida

In addition, educators must adapt their training methods to cultivate critical thinking and collaborative skills among future scientists. The next generation of scientists needs to be taught how to navigate the complexities of solution-driven research. "Integrating authentic research experiences and experiential learning into the curriculum has provided a way to develop students' ability to think critically and move beyond traditional methods of memorising scientific concepts," says Dr Tom D'Elia.

There is more to being a scientist than gaining scientific knowledge. "Scientists must be aware of public perception and the regulatory landscape. This is especially relevant for developing novel technology," explains Laura. "This is a huge issue, because even with the best technology in the world, if you don't successfully bring it to market, it's of no value to the consumer."

Embracing diversity for innovative solutions

Diversity plays a crucial role in promoting innovation within the scientific community. By embracing individuals from diverse backgrounds and experiences, researchers can gain fresh perspectives and approaches to problem-solving. In agriculture, for example, growers bring unique insights shaped by practical experience and economic considerations, enriching the research process with their perspectives. "A local grower and citrus consultant, Travis Murphy, took the time to drive us around the citrus groves and show us how growers think about the process of growing citrus," says Robert. "Learning how they took such a practical approach to dealing with all the problems a grower faces, and how they would adapt, created new ways of thinking for our research-oriented minds." Ultimately, the integration of diverse perspectives, collaborative approaches and solution-driven research methodologies holds the key to addressing pressing challenges facing society and the environment.

Developing transdisciplinary teams is essential, bringing together scientists from diverse backgrounds to collaborate closely with different sectors of agriculture. By promoting collaboration between researchers, regulators, healthcare professionals and industry representatives, researchers can develop biosecurity platforms that effectively address emerging threats. "Research and regulatory agencies need to work together to develop platforms with streamlined deregulation processes, and private industry needs to be engaged to support their investment into commercial delivery of these platforms where appropriate," says Robert. "We have all the capabilities to address this issue; we need the will to work together and make it happen."

Symbiont™ *success*

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"Innovation realised by bringing together researchers from different disciplines has seen the development of a new way to deliver therapeutics to citrus trees," says Robert. "This is a sustainable and biologically based therapeutic delivery platform called 'Symbiont™' that was developed to provide protection and symptom alleviation to citrus trees from huanglongbing (HLB)." This platform represents an effective approach to addressing HLB, without the need for genetically engineered citrus trees.

At the core of the Symbiont™ platform is the ability to stimulate localised plant cells to form a gall (or growth) on the trunk of citrus trees. Within these galls, termed Symbionts™, engineered citrus cells produce therapeutic molecules such as antimicrobial peptides or plant defence compounds. These molecules are then released into the plant's vascular system, targeting the bacterium responsible for HLB. Importantly, the engineered cells remain localised within the gall and cannot survive if removed from the plant, ensuring environmental safety.

"This platform is based on a method that naturally forms galls on trees that is induced by a commonly occurring bacterium called *Agrobacterium*," explains Robert. "We have demonstrated proof-of-concept of this method in greenhouse grown plants, where HLB-symptomatic potted citrus trees had reduced bacterial titre, reduced HLB, symptoms and more vigorous growth with larger leaves when Symbionts™ expressing antimicrobial peptides were developed on them. We are now conducting research to determine if it can be adapted to commercial citrus production."

Dr Taw Richardson

Chief Executive Officer, AgroSource, Inc.

The achievement of the Symbiont™ platform is down to the solution-driven collaborative approach the team has embraced. "HLB is a disease that is extremely difficult to manage because it affects every aspect of citrus biology, physiology and production," explains Lorenzo. "The ability to efficiently deliver molecules of interest inside the vascular system of a living tree required a team of individuals able to understand the different aspects of plant biology, chemistry and engineering."

Dr Taw Richardson adds, "Our major success is our current field trial programme for Symbiont™ technology on Florida citrus, taking a completely novel concept to an actual product in the field. This trial represents years of ground-breaking work by dedicated scientists and technicians in the lab and greenhouse, and the coordination of researchers at multiple organisations and with extensive communications regulatory agencies to collect supporting data."

The results from this field trial will provide valuable insights into the real-world effectiveness of the Symbiont™ platform in combatting HLB on a larger scale. If successful, this trial could pave the way for widespread adoption of the Symbiont™ platform in commercial citrus orchards, offering a sustainable and environmentally friendly alternative to traditional disease management strategies.

Further applications

The Symbiont™ technology can be used for more than just HLB and cherry X-disease. It can also help fight diseases that affect

crops like potatoes and tomatoes grown in fields. These crops are affected by *Liberibacter solanacearum*, a plant pathogen which is transmitted by the potato psyllid and is closely related to the HLB pathogen. Infected plants usually die within four to six weeks of infection, with potato tubers presenting distinct striped patterns and unpleasant taste, making them unsuitable for market. "We are currently using potato and tomato to rapidly screen Symbiont™ constructs for efficacy against *Liberibacter*," explains Rodney. "With some engineering ingenuity to deliver Symbiont™ to field crops, Symbiont™ may provide potato and tomato growers with a highly targeted tool to manage *Liberibacter solanacearum* while reducing insecticide use."

"Although the Symbiont™ platform is currently being developed to control pathogens, this technology may provide some truly novel mechanisms to control persistent insect pests such as codling moth in apples," explains Rodney. "This worm is currently managed using mating disruption, where orchards are flooded with codling moth sex pheromone so that males cannot locate females." However, this method requires pheromone disruptors, which can be laborious, expensive and prone to error. We are excited to initiate research where we develop Symbionts™ that can produce these natural, volatile sex pheromones. "We have already shown that Symbionts™ can produce complex molecules formed by multistep biosynthetic pathways," says Rodney. If successful, this opens the possibility of using Symbiont™ to deliver pheromones directly in orchards, reducing the need for synthetic disruptors and streamlining the mating disruption process. By inoculating pollination trees (or other non-crop plants) with Symbiont™, orchards could be flooded with codling moth sex pheromones more efficiently, offering a promising alternative to traditional mating disruption methods. While further research is required to refine and adapt Symbiont™ for this purpose, it demonstrates the adaptability of this technology beyond its original pathogen control application.

Building momentum

The team's success in developing the Symbiont™ platform has laid the foundation for ongoing research and development efforts. "HLB is a worldwide pathogen that has had a tremendous impact on global citrus production," says Robert. "Success in using our solution-driven approach to address this problem will be a major driver in global research activities for other invasive pest/disease issues." To maintain and build upon this momentum, continued investment in research is essential. This includes refining the platform further, identifying new therapeutic molecules, and conducting field trials to assess efficacy in real-world conditions. Additionally, collaboration and partnerships with academia, industry, government agencies, and growers are vital for knowledge exchange, resource-sharing and collective problem-solving.

Dr Mark Trimmer

President and Founding Partner, DunhamTrimmer LLC

As Dr Mark Trimmer explains, "It is vital we continue to challenge what is working and what is not and avoid committing to one approach. Continuous improvement should be the goal."

Effective communication is also crucial for maintaining visibility, garnering support and attracting funding. By communicating project achievements, milestones and impact to stakeholders, policymakers and the public, the team can amplify its reach and influence. "Finally, remaining adaptable and flexible in response to changing circumstances, new challenges and opportunities is essential," says Lorenzo. "Continuously reassessing strategies, adjusting plans and incorporating lessons learnt ensures resilience and success."

What does the future hold?

International opportunities for collaboration and partnerships hold great potential in addressing diseases such as HLB and enhancing global food security. "Establishing collaborations with international research institutions, universities, and organisations facilitates the exchange of knowledge, resources and expertise," says Lorenzo. "At the same time, seeking funding from international sources such as grants, venture capital and investment partnerships can provide the necessary resources to scale up and commercialise solutions globally." Additionally, capacity building and training initiatives play a crucial role in empowering international stakeholders, including growers, researchers and policymakers. By providing training programmes, workshops and educational materials, stakeholders can enhance their capacity to adopt and implement innovative solutions effectively, thereby contributing to global efforts in ensuring food security.

> **"It is vital we continue to challenge what is working and what is not and avoid committing to one approach."**

Overall, the future is full of excitement and promise. "As we learn to adapt how we conduct science to fit the rate at which we can now obtain and create data and knowledge, we have to adapt how we do science to harness that data and knowledge into deliverable solutions," says Robert. While the path ahead may present various challenges, advancements in technology, research and collaboration offer hope for combatting agricultural diseases sustainably. This collective research effort not only addresses immediate challenges but also holds invaluable lessons for the next generation of scientists. "We hope future scientists learn that they should not avoid uncomfortable situations; uncomfortable is where innovation often lies," says Robert. "Realise that your research can have a greater impact if you recognise it as an important piece of a much bigger puzzle and that you need to find the other pieces that fit with yours."

Can analytical chemistry make beer taste better?

Since beer was invented thousands of years ago, brewers have been modifying, adapting and experimenting with their recipes. Subtle changes to a beer's ingredients can have a noticeable impact on its flavour. At **Christopher Newport University** in the US, **Dr Ron Quinlan** is using analytical techniques to uncover the chemistry of beer. He hopes to demonstrate the real-world applications of analytical chemistry by helping brewers create the perfect pint.

Dr Ron Quinlan

Department of Molecular Biology and Chemistry, Christopher Newport University, USA

PROFILE

Field of research
Analytical chemistry

Research project
Analysing the chemistry of beer

Funder
US National Science Foundation (NSF)

Talk like an ...
analytical chemist

Brewing — the process of producing beer, which involves soaking malt in water to release sugars, followed by fermentation to produce alcohol

Fermentation — the process by which, during brewing, enzymes in yeast convert sugar (glucose) into alcohol (ethanol) and carbon dioxide:
$C_6H_{12}O_6 \rightarrow 2C_2H_5OH + 2CO_2$

Hop — a flower from the hemp family of plants, used to give flavour, aroma and bitterness to beer

Liquid chromatography — an analytical technique to separate a complex liquid solution into its chemical components

Malt — a cereal grain (most commonly barley) that has been soaked in water to begin germination, then dried to prevent further germination

Mass spectrometry — an analytical technique to identify chemical compounds in a sample

Humans have been drinking beer for thousands of years. The world's first beer recipe is found in an ancient prayer to Ninkasi, the goddess of beer, worshiped by inhabitants of ancient Mesopotamia. Workers building the Pyramids of Giza in ancient Egypt were given a daily ration of beer to keep them refreshed and hydrated. And beer is still important today. In 2019, the beer industry supported over 23 million jobs around the world and contributed $555 billion to the global economy. In many countries, beer is not only an integral part of society, but a source of national pride. From Heineken in the Netherlands to Guiness in Ireland, each beer has its own unique identity and flavour.

At Christopher Newport University, Dr Ron Quinlan is leading a team of analytical chemists and commercial brewers to uncover the chemical composition of beer. He hopes that by understanding how environmental conditions impact the chemistry of beer ingredients, brewers will have more control over the taste of their beers.

What is beer made from?

"Beer contains four key ingredients: malt, hops, yeast and water," explains Kevin Kingsbury, Head Brewer at Tradition Brewing. Malt and hops contribute to the beer's flavour, as well as providing health benefits due to the vitamins, essential oils and acids they contain. "Different combinations of these compounds can lead to designed changes in the beer's bitterness, aroma and taste," explains Kevin. Malt also creates the beer's colour and provides the sugars which the yeast converts into alcohol during fermentation.

Celina loads hop samples into the liquid chromatograph

How do environmental conditions influence the taste of beer?

A beer's flavour is dependent on its ingredients and the brewing process, thanks to the chemistry of the malt, hops and water, and the chemical changes that occur during fermentation. Most of a beer's volume is water, so local water chemistry influences the beer's taste. The specific chemical compounds found in malt and hops depend on the environment in which they are grown. "Changing the environmental conditions changes the chemical ratios within the same plant species," explains Ron. "And changing the ratios of the chemicals in beer results in changes in the flavour."

As climate change causes environmental conditions to change, brewers around the world will have to adapt if they are to preserve their signature tastes. "This research is exciting because we're just beginning to understand how the growing environment of malt and hops influences the flavour of beer," says Ron.

How is the team chemically analysing beer?

Ron and the team are combining two analytical techniques, liquid chromatography and mass spectrometry, to determine the chemical composition of beer and beer ingredients. Liquid chromatography separates a sample into its chemical components, then mass spectrometry analyses each individual component and identifies what chemical compounds it contains. "When we put the two techniques together, we can determine which compounds are present in the beer with very high accuracy and precision," explains Celina Paoletta, a student in Ron's lab.

> ***"Changing the ratios of the chemicals in beer results in changes in the flavour."***

The team uses these techniques to determine which compounds are produced by the hops and malt before they go into the beer. "We then track the compounds through the brewing process and into the finished beer," says Chris Balog, another student. "This allows us to discover previously unidentified chemical reactions taking place during the brewing process."

Through this research project, Ron is keen to highlight the real-world applications of analytical chemistry. "It's easy for analytical chemists to get caught up in their lab-based methods," he explains. "Collaborating with industry partners, like Tradition Brewing, means we are working on research that has an impact on society." This partnership also means students gain practical experience of applying their analytical chemistry knowledge to address real-world challenges in a fun and engaging project.

What has the team discovered?

So far, the team has observed that hops and malt grown in different environments have different ratios of chemical compounds. "For example, if the same species of hop is grown in the US and Europe, each plant will contain the same types of compounds but in different concentrations," says Ron. He is now trying to determine how chemical reactions during the brewing process cause these changes. Kevin explains, "What we do know is that growing the same species of hop in different environments, then brewing them with the same recipe into beer, will result in slightly different beer chemistry and, therefore, different tastes."

How will this research impact the beer industry?

By understanding exactly how environmental conditions influence the chemistry of hops and malt, the team hopes that farmers will be able to grow hops and malt with specific chemical profiles, while tailoring their agricultural practices to be more efficient. Brewers could then brew these hops and malt into new beers with specific tastes or health benefits. For example, some chemical compounds are thought to help protect against cancer. If hops and malt could be grown to contain these compounds, they could be brewed into beers with targeted health benefits.

As climate change continues to impact food supplies, Ron, Kevin, Celina and Chris are ensuring that brewers will continue to brew tasty beer that contributes to a huge global industry.

About *analytical chemistry*

"According to the chemist, C.N. Reilly, analytical chemistry is what analytical chemists do," jokes Ron. "In fact, analytical chemistry is the study of how matter interacts and behaves as it is undergoing chemical analysis." Here, Ron is pointing out the subtle difference between analytical chemistry and chemical analysis. While chemical analysis aims to determine what matter is made up of, analytical chemistry is focused on the methods that are used to do this, such as liquid chromatography and mass spectrometry. "Analytical chemists seek to find and correct errors in current methods of analysing chemical compounds, and to discover new analytical chemistry techniques," explains Ron.

What skills do analytical chemists need?

Patience is a key skill for analytical chemists. "We constantly reanalyse the same sample with small changes in the method," says Ron. This might mean repeating an analysis multiple times with slightly different volumes of the sample to discover how this impacts the results, or performing the same analysis again and again to calculate the reproducibility of the method. Therefore, analytical chemists must also have good attention to detail and an ability to work precisely and accurately.

What are the joys of analytical chemistry?

"Analytical chemistry is applicable to every other science," says Ron. "Do you want to study organic chemistry, pharmaceuticals, cellular metabolism or neurological disorders? For all of these, you need an analytical chemist to make your measurements."

"I enjoy the complexity and attention to detail that is inherent in analytical chemistry," says Celina. "Studying analytical chemistry fosters critical thinking and problem-solving skills. It also teaches you how to ask better questions and how to fail forward, and you get to learn more about the world in the process."

Pathway from school to *analytical chemistry*

At school and beyond, studying chemistry is crucial for learning the theory behind chemical compounds and reactions and the practical methods of chemical analysis. A strong background in mathematics is also important for statistically analysing data, and a good understanding of biology and physics will provide background knowledge for many applications of analytical chemistry.

Take part in chemistry events and competitions, such as local and national chemistry olympiads, to gain hands-on chemistry experience: **www.acs.org/education/students/highschool/olympiad.html**

Practical experience in a chemistry laboratory will be incredibly valuable. When considering chemistry degree options at university, check how much laboratory work you will do. "I encourage students to take as many laboratory courses as they can," says Ron. You can also look for internships with chemistry-based industries and opportunities to volunteer with research labs.

Explore careers in *analytical chemistry*

"The career opportunities as an analytical chemist are endless," says Ron. In addition to helping brewers develop tastier beer, you could apply your skills in fields such as water quality monitoring, environmental assessment, pharmaceutical development, chemical production and food science.

The American Chemical Society (**www.acs.org/education.html**) and the Royal Society of Chemists (**www.edu.rsc.org**) have a wealth of educational and careers resources for students.

Q&A
Meet *Ron*

Who inspired you to be a chemist?

My father is a chemist, so I spent a lot of time in a lab when I was growing up. We were always having fun with science projects. For many years, I dreamt of being a medical doctor, but after just a couple of weeks in college, I changed my mind and switched my focus to chemistry. During my undergraduate degree, I participated in a summer research project with one of my professors, which is when I decided I wanted to become a chemist. Once I got the research bug, I was hooked!

How did you apply your chemistry knowledge in your previous job?

After finishing my PhD, I spent four years working in research and development for the US Navy, where I helped develop lithium-ion batteries. I characterised the chemistry of the materials used to make the battery electrodes and examined whether they degraded over time as the battery was repeatedly used and recharged. This work introduced me to many new analytical chemistry techniques, and I learnt how to combine these with methods I was already familiar with.

What motivated you to focus your research on beer?

I wanted an engaging project to get my chemistry undergraduate students interested in analytical chemistry. My research student, Celina, was interested in food science. She has a great sense of smell and taste, so we decided to do some chemical analysis of hops. Then Chris approached me as he wanted to study malt for a project for his environmental science degree. From there, the beer analysis took off. We partnered with Tradition Brewing, a local brewery in town which makes a lot of great beer. Kevin is a great teacher, and his team is important for keeping the project fun. Studying beer is a great way to learn about and apply analytical chemistry. And, of course, beer makes the research taste better!

Ron's *top tips*

1. Keep asking questions: how and why do things work?

2. Don't get discouraged when things go wrong. If it were easy, someone else would have already done it.

A CURE for education: how can genuine scientific experiences inspire future scientists?

What is it like to be a research scientist conducting hands-on experiments in a working lab? How well can science lessons prepare – and encourage – students for careers in STEM? **Dr Ying Gao**, assistant professor from **Nantong University, Xinglin College,** in China and currently based at **Jackson State University** in the US, is investigating how course-based undergraduate research experiences (CUREs) can transform the learning experience and encourage students to think like real scientists.

Dr Ying Gao

Assistant Professor at Nantong University, Xinling College, China, and doctoral student at the Department of Elementary and Early Childhood Education, College of Education and Human Development, Jackson State University, USA

PROFILE

Field of research
Education research

Research project
Using course-based undergraduate research experiences to improve the experience of African American geotechnical engineering learners

Funders
US National Science Foundation (NSF)
Project number: 633242

Department of Education in Jiangsu Province, China
Project number: 2021JSJG357

Department of Education in Jiangsu Province, China
Project number: 2024JSJG168

Talk like an ... education researcher

Collaboration — working with other people to reach a shared goal. During CUREs, learners are encouraged to collaborate with each other to form new ideas and support each other's learning

Course-based undergraduate research experience (CURE) — a learning opportunity that allows students to take part in and learn from real-world scientific research projects

Discovery — the act of finding something new. During CUREs, learners are not simply given information, but are expected to discover it for themselves

Historically black colleges and universities (HBCUs) — higher education institutions that were established to serve African American learners specifically

Scientific mindset — an outlook on life that is driven by curiosity and involves questioning and testing hypotheses about the world around us

STEM — science, technology, engineering and mathematics

Science lessons need to teach the wonders of the known universe in classrooms or educational settings, often through old textbooks and in relatively short amounts of time. The miracle of life is boxed into graphs and diagrams, while the mysteries of time and space are sucked into a black hole of incomprehensible equations and formulae!

Of course, education has to start somewhere, and it is important to learn fundamental knowledge and basic practical skills to become a scientist. However, it can be hard to get to grips with difficult concepts from books and PowerPoint presentations or to feel inspired by an experiment that has been conducted countless times in classrooms all over the world.

At its core, science is about discovery. Surely, we can find a way to learn these skills in a manner that also teaches us to adopt the scientific mindset. A mindset that is curious, inquisitive and that asks questions about the world around it.

Dr Ying Gao, based at Nantong University, is an education researcher who has been studying at the College of Education and Human Development at Jackson State University, investigating the potential of a new educational model to do just that. Ying's research is focused on a geotechnical engineering course that uses course-based undergraduate research experiences (CUREs) to give its learners the chance to gain practical skills and develop a scientific mindset through participation in genuine scientific research.

What is different about CURE courses?

"In traditional laboratory classes, learners explore the scientific world in a fixed routine with a variety of scientific exercises," says Ying. "Learners carry out predetermined scientific research according to instructions from an experiment manual." This way of learning, as many of us have experienced, can feel dull and unproductive.

"Contrary to traditional lab courses, CUREs create a laboratory learning environment in which learners are completely absorbed in a variety of novel research," explains Ying. Students taking part in CUREs are fully immersed in real-world scientific research; they learn how to create research questions and design studies, collect and interpret data, and communicate their findings to other people.

For example, learners on the geotechnical engineering course that Ying has been focusing on take part in a research project investigating the potential for drones to improve land surveys. Land surveying is a fundamental part of all civil engineering projects. As part of their CURE, learners use drones to collect data on research sites such as dams and bridges.

"With the assistance of modern technology, learners have the opportunity to apply what they have learnt to a real-world project," explains Ying. "Taking part in these experiences gives learners a deep understanding and an intuitive feeling of scientific practice."

What are the benefits of CURE courses?

To compare CURE courses with traditional courses, Ying surveyed learners from both course types before the start and at the end of their courses. These surveys asked learners about different aspects of their course, such as how much they were encouraged to collaborate with others, how much they were expected to use their own initiative, and what their career aspirations were.

The results from these surveys show that the CURE model inspires learners to seek further education in engineering and prepare themselves for engineering jobs in the future. Ying explains, "Lab courses embedded with CURE elements can improve learners' competence in experimental design and data analysis, inspire their enthusiasm in science, and convince them to continue with their studies."

These results are particularly encouraging because Ying's research took place at Jackson State University, one of the largest Historically Black Colleges and Universities (HBCUS) in the US. Before the civil rights movement in the 1960s, many American colleges and universities limited their intake of, or refused entry to, African American students. HBCUs are higher education institutions that were created to serve African Americans.

Why are CURE courses so important at HBCUs?

"In 2017, the number of African American learners enrolled by American public colleges and universities in STEM majors was only one-fifth of the number of white learners," says Ying. African American learners also have higher drop-out rates and lower graduation rates than other learners. "As a result, the involvement of African Americans in STEM occupations is strikingly low," she adds.

These worrying statistics are the result of a whole host of barriers – from a lack of mentorship and support, to fewer opportunities, to more overt forms of discrimination – that can make higher education more challenging for African American learners.

Implementing CURE courses at more HBCUs could help to improve the situation. Findings from Ying's research show that the CURE course she implemented improved learners' self-confidence and encouraged more of them to consider careers in STEM fields.

Scientific research that impacts all of society needs researchers from a range of backgrounds and with a range of perspectives. Encouraging and developing African American STEM experts is a vital part of the diversity we need to benefit us all.

What are Ying's next steps?

Ying will continue to study CURE courses and their impacts on African American learners. In future studies, she will interview learners to gain a deeper understanding of their survey responses. These interviews, along with advice from teaching experts, will allow Ying and her fellow educators to adapt and improve the CURE model.

"We expect that instructors from different courses at the university will adopt the CURE model in the future," says Ying. "We hope that this will strengthen STEM education for our African American undergraduates, help to cultivate their talents and prepare them to compete in the global job market."

About *education research*

Education is one of the most important aspects of our development as human beings. A good education allows us to communicate with other people, develop new skills and understand the world arounds us. Without a proper education, we may struggle to feel confident socially, find work, take care of ourselves and lead a fulfilling life.

Education research is the process of studying, testing and, ultimately, improving our education practices. Education researchers aim to understand the mechanisms by which humans learn in order to identify new and better ways of teaching.

Over the last few years, one of the big questions in education research has been how best to integrate technology into education. During the COVID-19 pandemic, this question was put to the test as schools and universities around the world were forced to move all of their teaching online.

Overnight, teachers and learners had to adapt to video calls and virtual classrooms. How long can learners pay attention on a video call? How does a lack of social contact affect learning? Can teachers support students properly without face-to-face interactions? These are the types of questions that education researchers are still trying to answer, with many concerned about the consequences lockdowns had on schools and young people.

While it is clear that technology cannot replace in-person learning, there is still huge potential for it to enhance and augment our teaching methods. In fact, it is hard to imagine how a school could function these days without access to computers, the internet and smart boards. As technology continues to evolve, so too does its place in the classroom.

One new technology, augmented reality, is already being used in some classrooms. For example, medical students use simulation software to practice surgical procedures, whilst some mathematics teachers are using augmented reality to teach trigonometry (**futurumcareers.com/how-augmented-reality-can-help-you-learn-trigonometry**).

Pathway from school to *education research*

Education research is often offered as a post-graduate course such as a master's degree or a PhD. To qualify for these courses, it is likely that you will need to have achieved a good grade in a related undergraduate course.

Undergraduate courses in the social sciences (such as psychology and sociology), humanities (history, geography, etc.), and liberal arts (literature, philosophy, etc.) could all prepare you for a postgraduate course in education research.

During an education research post-graduate course, you will learn about different education methods, how to design studies and conduct research, and about the impacts that education has on society.

Throughout your studies, you will need to learn skills such as statistics, research methodology and experimental design so that you are able to conduct impactful research when you graduate.

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Explore careers in *education research*

Societies such as The American Educational Research Association (**aera.net**), The Society for Educational Studies (**soc-for-ed-studies.org.uk**), and The British Educational Research Association (**bera.ac.uk**) are great places to learn about current topics in education research, connect with other education researchers and get careers advice from more experienced people.

Some education researchers may be employed by a university to conduct research into many aspects of education including the societal importance of education, inequalities in education, educational psychology, and the study of human learning.

Other education researchers may be employed by schools, education departments or teaching companies to help them improve their practices and provide a better education for students.

A great way to find out more about a career in education research is to talk to an education researcher. Why not get in touch with the education department at your dream university and see if you can chat to one of their researchers about their work?

Q&A

Meet *Ying*

Who inspired you to become an education researcher?
My supervisors, Professor Yin and Assistant Professor Wen, who have done an outstanding job in their research fields. Their commitment and diligence inspired me a lot.

What experiences have shaped your own career?
When I had teaching practice as a student teacher in a poorly-equipped primary school in China for half a year, I was deeply touched by students' eagerness to learn knowledge and their optimism towards life. Education can help you to see a bigger world which you have never experienced before. Education can inspire the light in your heart and motivate you to pursue your own dreams.

What are your proudest career achievements so far?
I was awarded an 'Excellence in Teaching' prize in 2019 in our city.

What are your aims for the future?
To help more students not only acquire knowledge but also inspire them to realise their dreams. To make their hopes and dreams reality. To light their path to career success and life satisfaction.

> ***"Education can help you to see a bigger world which you have never experienced before."***

Ying's *top tips*

1. Be honest with your research.

2. Focus on your research.

3. Avoid distractions!

4. Keep moving forward.

Learning in the spotlight: cutting-edge technology to help performers reach their full potential

Whether in music, business, sport or any other performance field, performing in front of an audience is very different from practising. The pressure performers feel can affect the quality of their performance. **Aaron Williamon, Richard Bland** and **George Waddell** have been leading efforts at London's **Royal College of Music** to develop its **Performance Laboratory** into a world-class simulation facility. It uses the latest tech to help performers experience factors that can affect a performance and learn how to manage them effectively.

Professor Aaron Williamon

Head of the Centre for Performance Science

Richard Bland

Head of Digital and Production

Dr George Waddell

Performance Research and Innovation Fellow

Royal College of Music, London, UK

Fields of research
Performance science, music technology

Research project
Leading the creation of state-of-the-art performance laboratories that use the latest performance simulation technology and science

Funders
Arts and Humanities Research Council (AHRC), World Class Laboratories Fund (WCL) grant ref. AH/X010090/1

PROFILES

Glossary

Acoustics — the properties of a space that affect how sound is transmitted in it

Performance anxiety — extreme nervousness experienced before or during a live performance

Performance science — the study of human performance across disciplines, including sport, music, theatre, and business

Simulation — a model that imitates a real activity

The Royal College of Music (RCM) in London is one of the most esteemed music conservatoires in the world, ranked no 1 for Music and Performing Arts in the 2024 QS World University Rankings. Much of this reputation stems from advancing the science of performance and embracing new technologies to ensure that the college stays at the cutting edge. This important role within the cultural and creative economy has led the RCM to develop pioneering performance facilities that use the latest simulation technologies to generate immersive experiences that performers can use to hone their skills.

Professor Aaron Williamon heads the Royal College of Music's Centre for Performance Science. "The team is collaborating with RCM musicians to deliver learning experiences modelled on the dynamic environments of the world's leading performance spaces," he says. This team includes Richard Bland, Head of RCM Digital and Production, and Dr George Waddell, RCM Performance Research and Innovation Fellow. Together, they are combining their areas of expertise to guide the development of these new resources.

The Performance Laboratory

Having hosted several decades of performance research, the Royal College of Music is at the forefront of performance science. The college has operated a Performance Simulator since 2011 that has guided countless students in honing their performance skills, but it is now time for an upgrade. "This major infrastructure investment has transformed the existing Performance Simulator through state-of-the-art motion


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capture systems and the very latest acoustic and visual simulation technology," explains Aaron.

"Our new Performance Laboratory offers unparalleled opportunities for students to prepare for the challenges of the modern music industry, as well as propelling research across multiple disciplines," says Aaron.

Improving performance and wellbeing

A career in any performance field has the potential to be intensely stressful, and live performances often act as focal points for this pressure. "We know that performing feels different to rehearsal," says George. "Our bodies and brains respond differently under stressful conditions, and both the build-up to a performance and the performance itself can provoke anxiety." Live performances can be high-stakes moments, and if they do not go to plan, they can negatively impact performers' careers.

Simulations can recreate these performance settings without the risks of lost opportunities, offering a controlled environment where students can learn how to deal with the pressure of performance – and even use it to their advantage. "The Laboratory can help students learn to harness the charged atmosphere and extra physical energy of a live event, using it to enhance rather than inhibit their performances," says George.

The team's development of the Performance Laboratory is not just about making students better performers. It is also about supporting personal health and wellbeing. Without support systems in place, it is all too easy for performers to develop physical or mental health issues that can have grave impacts on their quality of life and career longevity. For instance, nervous musicians may suffer from self-doubt, an overall lack of confidence, or elevated physical responses, such as increased heart rate, which can affect the quality of their performances. They can be tempted to turn to alcohol or other substances to control this – a practice which can all too easily become self-destructive.

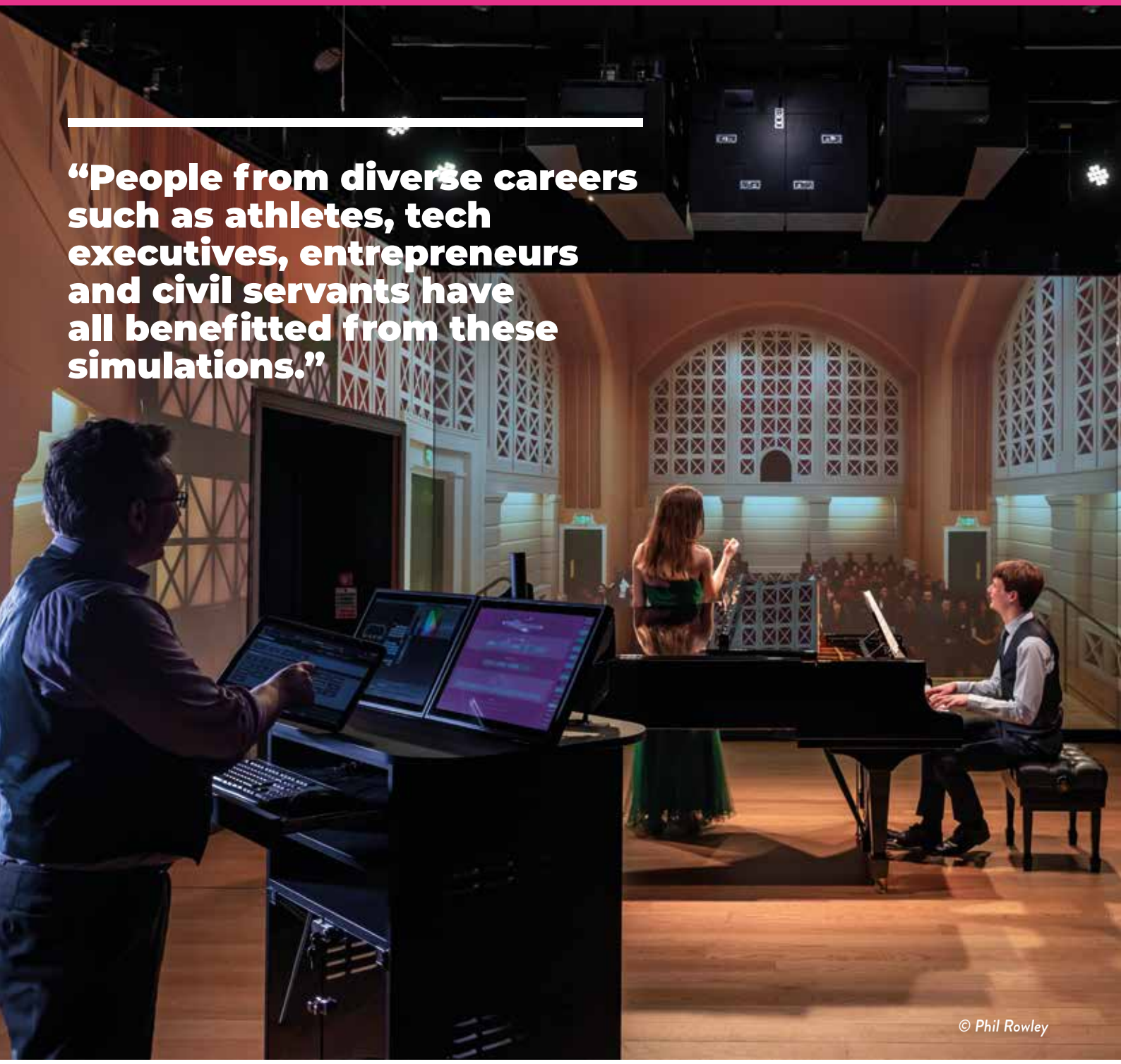
When practising in simulated performance environments, musicians can focus on developing healthy alternative techniques instead, such as mental skills and physical support exercises. "The Laboratory lets them confront the pressure of performance in a controlled space and develop healthy, sustainable strategies to stay in control," says George.

State-of-the-art technology

Such a groundbreaking educational space as the Performance Laboratory requires sophisticated technology. "The RCM's performance studio has been transformed to include a state-of-the-art Meyer Sound Constellation system, which incorporates dozens of speakers into the walls and ceiling," explains Richard. "This technology can be set to emulate specific performance spaces, or even create entirely new acoustics." The acoustics of a space make a big difference to a performance: an echoey church provides a very different audio experience to a soundproof recording studio, for instance. Typically, musicians performing at an unfamiliar venue have to adapt to its particular acoustics immediately before or even during a performance. The Performance Laboratory's capacity to simulate acoustic differences means this big unknown can be explored much earlier.

Alongside acoustic features, the space also includes wall-height screens that display visual simulations of performance venues. These visualisations are driven by Unreal Engine, a software platform used for immersive video games. "We can set the space to display interactive models of the RCM's own concert hall and opera theatre, including reactive virtual audiences and audition panels," says Aaron. "And we can manipulate these conditions – for instance, changing the receptiveness of the audience, triggering a particular disruption, or setting up an intimidating panel."

Such challenges are likely to arise within a musician's career, so being able to experience them in a controlled environment can be highly valuable to hone their skills in stage presence, communication and stress management. Additionally, the Laboratory includes opportunities for performers to use trackers to monitor themselves – being able to see through data how their breathing or movements change during a performance, for instance. This can help them understand exactly how their bodies respond to performance and, if these responses could be improved, take steps to change them.



“People from diverse careers such as athletes, tech executives, entrepreneurs and civil servants have all benefitted from these simulations.”

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Crossing disciplines

Available for commercial hire, the benefits of the Performance Laboratory go far beyond music. “The Performance Laboratory has been used as a training facility for public speaking, interviews and business,” says Aaron. “People from diverse careers such as athletes, tech executives, entrepreneurs and civil servants have all benefitted from these simulations.” Any career that involves a degree of performance can benefit from its lessons, helping people to hone their skills and deliver ‘performances’ to the best of their abilities.

This demonstrates how performance is an art — and a science — itself, and many of its lessons are transferable across disciplines. “The Laboratory helps performers of all kinds, from musicians to business leaders, to realise that the performance starts as soon as you walk onto the ‘stage’ and continues for some time after you have left,” says George. “In the Laboratory, we have seen performers improve their handling of those brief moments outside of the main performance, helping us see the benefit of our approach.” The space also provides a valuable research tool for advancing performance science further. The team undertakes cutting edge research across the arts, business, sport, medicine and education.

By helping performers to improve their art and supporting their wellbeing, the Performance Laboratory is a prime example of how the Royal College of Music maintains its position at the forefront of music education and performance practice. “Bringing together this collection of technologies indicates the commitment of the Royal College of Music in supporting the next generation of musicians,” says Richard. “We are not just embracing, but actively advancing digital technologies for research, learning and performance.”

Meet *George*

My undergraduate degree was in piano performance. An 'Introduction to Psychology' course opened my eyes to what the social sciences could teach us performers, and how performers can contribute to scientific knowledge. When I learned that the Royal College of Music was home to the Centre for Performance Science, full of like-minded people, I was inspired to apply for their PhD programme. I then joined the faculty in 2016 and have been here ever since.

I am the RCM's Performance Research and Innovation Fellow. I study how performers learn and are evaluated, including how technology can enhance these processes. I then use this knowledge to help design and deliver training for performers of all kinds and ensure that the latest knowledge and tools are embedded within our various teaching programmes.

It can be difficult for performers to imagine the kinds of environments in which they will perform. The Laboratory lets us deliver and study these environments through real experiences, so performers can understand exactly how they respond to a performance space.

Fear of judgement by others is a leading cause of performance anxiety. Evaluations from audiences or audition panels can shape a performer's entire career. The Laboratory helps performers put forward the best version of themselves, and to get used to the feeling of being watched and assessed. It also helps us understand how decision-making is affected by stressful environments.

> ***The Laboratory helps us consider the parts of performance that are often overlooked.***

Every time I enter the Performance Laboratory, I feel myself switching into performance mode. This is after ten years of working with our performance simulations! Watching people react to the space for the first time never gets old.

Performance science has come a long way in recent years. However, there's still much we don't know about what goes on in the minds and bodies of performers when under the spotlight. The Laboratory helps us consider the parts of performance that are often overlooked.

Psychology, physiology and the social sciences are crucial to understanding performance science. Performance science is about the people who perform, so we need to understand how they think, learn, communicate and behave.

I love working with some of the world's top performers. As well as playing a small role in helping them, I am also learning from them, so that everyone can enhance their own day-to-day performance. It's a constant thrill.

It's a privilege to work at the RCM. I am honoured to be able to shape how performance is learned and advanced by the latest technologies. My ambition is to take what we learn and create here and find ways to share it across the world, so that performers can excel wherever they are.

George's *top tips*

1. Seek out the links between the things you do and love, no matter how unrelated they seem.
2. Always be the one eager to ask questions and to learn about what other people do.

Master of Science in *Performance Science*

The Royal College of Music offers an internationally distinctive Master of Science (MSc) in Performance Science which examines the art and science of performance in real-world educational and professional contexts, including the roles technology can play. The programme encourages students to engage with key aspects of performance psychology and education, performers' health and wellbeing, arts and health, and research methods. For more information visit **www.rcm.ac.uk/MSc**

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Meet *Richard*

I first thought about undertaking a degree in electronic engineering. I changed my mind and pursued music technology, and loved being able to study a wide range of disciplines. I was able to study studio and live recording, video and lighting, and worked with a wide range of musicians and genres.

After graduating, I worked as a freelance sound engineer for eight years. I often recorded live concerts and sessions across the UK. I then took on a job looking after a student tech team at an academy in West London. It was highly fulfilling, and the team achieved great things. Many of my students went on to study and work in the industry, and it's a great pleasure when I occasionally get to work with them at gigs.

I was 'Hardware Lead' for the development of the Performance Laboratory. It was my responsibility to specify the equipment and systems that could realise the vision that Aaron and George had. I was already convinced that the college needed a venue with a Constellation active acoustic system, so was delighted to have the opportunity to bring my skills and knowledge to the project.

The space is a unique tool for researching the effects of acoustics on performance. We already have students investigating these questions. In the Performance Laboratory, we can carefully control and change parameters while the performer remains in the same physical space.

The largest challenge in this project was finding the best method for displaying images. LED walls were out of the question because they reflect a lot of sound, making them incompatible with the audio system. We settled on projection with acoustically transparent fabric. We then had to make housings for the projectors to reduce the sounds they made, while positioning them so performers can get close to the screen without casting shadows.

It has been very rewarding to see such a transformation of a previously under-appreciated space. Now, the Performance Laboratory is one of the most sought-after spaces at the college. Seeing the excitement from students and staff as they experiment with different acoustics is fantastic.

My understanding of and passion for performance science has exploded! The Centre of Performance Science does truly incredible work. I have always had a passion for science and music, and seeing the two in action and delivering results is truly thrilling to me.

I've taken on quite a few large orchestral recordings in my career so far. This has included sessions with the BBC Concert Orchestra and live recordings with the London Philharmonic Orchestra, among several others. I also worked on a production of Peter Grimes, an opera by Benjamin Britten, which we recorded on Aldeburgh Beach – a challenging venue but highly rewarding!

I am very passionate about education. I want to be on the user end of the new simulator, studying and developing ideas further. Looking ahead, I would also like to help students to further embrace technology, as there are so many opportunities for it to enhance what we do as musicians.

Richard's *top tip*

Ask questions and follow your passions. If you're interested in something but aren't sure if it'll be right for you, find someone making a career of it and ask them questions. You'll find they'll be delighted to share their passion, and you'll likely find that it's infectious!

Pathway from school to *music technology*

Higher-level music technology courses often have flexible entry requirements. A solid understanding of music, through taking it as a school subject and/or playing one or several instruments to a high standard, is recommended. Other useful subjects to take can include physics, mathematics, media studies and computer science.

Many universities and colleges offer undergraduate or higher-education courses in music technology. These courses typically involve the development of both practical skills and theoretical understanding. Subject matter is likely to cover audio post-production, technologies for live and recorded performances, and intersections between music and other media such as film and television.

Editing skills

Getting to grips with audio and video editing software is highly recommended for a career in music technology. Good audio software options to try out include:

- Garageband, free for Mac computers
- Bandlab, free across operating systems, which can also be compatible with DAW Cakewalk on PC
- Reaper, free to trial and licensed at a cost, which has more advanced features.

And for video editing software:

- iMovie, free for Mac computers
- DaVinci Resolve, free options for Mac and PC
- Shotcut, free for Mac or PC.

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About *music technology*

The intersection between music and technology is an exciting space. Technology has huge potential to enhance music – from synthesising soundtracks to augmenting live performances. Working in this field involves a deep understanding of how audio systems and acoustics work, as well as an appreciation of sound quality and emotional expression through music.

Typically, a career in music technology involves working daily with audio equipment. This includes microphones and other recording equipment, as well as processing techniques and software, such as MIDI (musical instrument digital interface), mixing and effects. Usually, people who enter careers in music technology enjoy using such equipment to create high-quality audio outputs.

Explore careers in *music technology*

Qualifications in music technology can lead to a broad range of careers. Some options include:

Sound technician: using equipment and collaborating with performers to record and produce music and other audio. Visit Prospects to find out more: **www.prospects.ac.uk/job-profiles/sound-technician-broadcasting-film-video**

Sound engineer: recording music, speech and sound effects with a technical and creative consideration of music: **www.prospects.ac.uk/job-profiles/sound-engineer**

Broadcast engineer: managing equipment to ensure that television and/or radio broadcasts air with a high sound and visual quality: **www.prospects.ac.uk/job-profiles/broadcast-engineer**

This article from MusicTech gives a rapid overview of ways into a career in music technology, including academic qualifications, skills development, teaching, internships and writing: **musictech.com/guides/essential-guide/how-to-make-career-music-technology**

The power of music for physical and mental health

Professor Gilles Comeau, Director of the **University of Ottawa's Music and Health Research Institute (MHRI)** and of the **Music and Mental Health Research Clinic** at **The Royal**, shares his belief in the power of music for improving health and well-being, and the importance of everyone having access to these opportunities.

The mental health benefits of music

Have you ever felt happier after listening to music, playing an instrument, singing a song or dancing along to your favourite tune? Interacting with music can have significant benefits for both your physical and mental health; music can play an important role in your overall well-being.

"Participating in musical activities can help cognitive function, reduce the risk of developing mental illnesses and reduce the severity of existing mental health conditions," explains Gilles. "Engaging with music triggers the release of dopamine, the 'feel-good' hormone that elicits feelings of pleasure and reward." This means that whether listening to your favourite band through your headphones while travelling on the bus, strumming to yourself on the guitar or singing in the shower, all forms of musical engagement are hugely beneficial.

However, while these individual interactions with music can boost your mood and cause noticeable benefits to your mental health, combining music interactions with social interactions provides extra advantages. Playing an instrument in an orchestra, singing in a choir, starting a band with fellow musicians or attending a concert with friends all enhance the mental health benefits of music, thanks to the addition of other people and the social interactions they bring. Gilles describes collective music-making as a form of social cohesion that has the power to connect people, providing the additional benefits of promoting friendships and increasing social connectivity.

> ***"Engaging with music triggers the release of dopamine, the 'feel-good' hormone that elicits feelings of pleasure and reward."***

Other health benefits of music

Playing an instrument requires concentration and coordination and can be considered an 'exercise for the brain'. It can also improve lung function, posture and fitness, as can singing and dancing along to music. Research has demonstrated that music participation involving movement is especially impactful for improving physical and mental health. "Musical activities that involve movement build strength and motor control," explains Gilles. "The dual tasks of listening to music and translating what is heard into movement have benefits to physical and cognitive health."

Improving music inclusivity and accessibility

Gilles is determined that everyone has the opportunity to engage with music and benefit from musical interactions. Unfortunately, this is not yet the case. "People with mental health issues, physical limitations or cognitive impairments often experience an unwelcome reception when trying to involve themselves in musical activities," says Gilles.

Removing these barriers is incredibly important, as everyone has the right to interact with music. "The Human Rights Act emphasises the need to provide equal opportunities for engagement in the arts," says Gilles. "That means all people should

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have the chance to foster their artistic aspirations and take advantage of the health benefits of music participation."

"Interestingly, sport is widely recognised as an important platform for inclusion and well-being for people with impairments," notes Gilles. "Sport has played a key role in advancing equity, through programmes such as the Paralympic Games. However, nothing similar exists for music, despite music being arguably just as universal and as important for health and well-being. I hope to see music-making positioned in a similar way."

A focus on community-based music for health and well-being

In May 2024, the MHRI is hosting a conference (**www.uottawa.ca/research-innovation/music-health/events/conference-2024**) focused on how community-based music programmes improve health and well-being. This multidisciplinary event will bring together researchers and practitioners from a wide range of fields, including music education, psychology, social sciences, neuroscience and health sciences, to explore how the power of music can be harnessed for improving health and well-being. People with lived experiences of using music to improve health and well-being will also share their stories. "By creating a rich environment that combines science and art, theory and practice, this event aims to be a catalyst for the development of strong research on community-based music, health and well-being," says Gilles. The conference will showcase the work of Canadian organisations that are leading the way in promoting music accessibility and include workshops to demonstrate practical ways to link music and health through community-based programmes. Gilles and his colleagues hope this conference will encourage researchers, music educators and healthcare professionals to promote music as a tool for improving physical and mental health.

How could you use music to improve your well-being?

> ***"The dual tasks of listening to music and translating what is heard into movement have benefits to physical and cognitive health."***

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