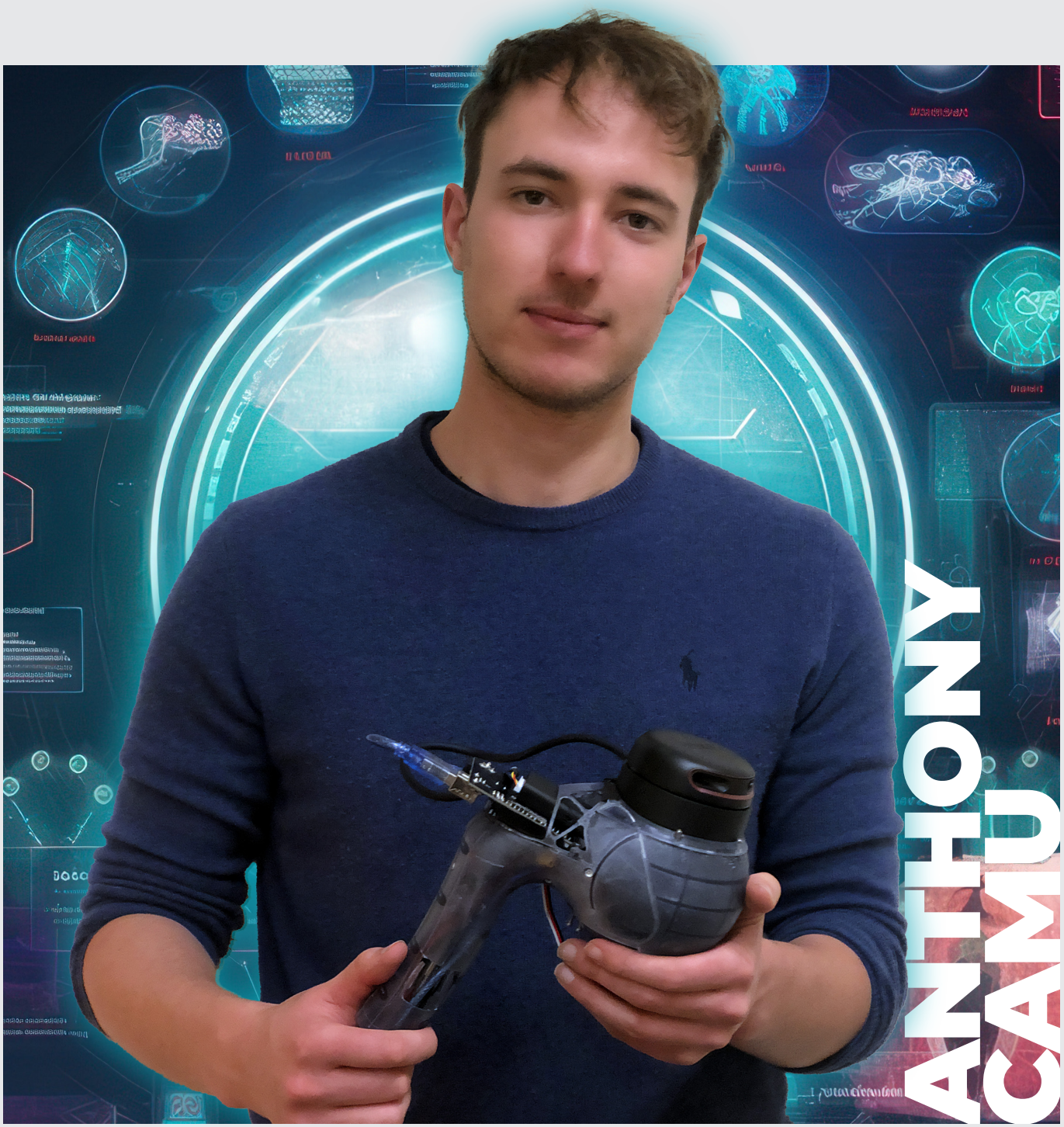
futurum

ISSUE 22
September 2023

Inspiring the next generation

futurumcareers.com



ANTHONY CAMU
Innovate UK's Young Innovators Award winner, inventor and entrepreneur

AMGEN FOUNDATION
Committed to advancing excellence in science education

FUTURUM AT FIVE!
We celebrate five years of Futurum Careers magazine

Be part of a STEM and SHAPE education community

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

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

What's in it for you?

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

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

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

A note about your privacy

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

WELCOME

ISSUE 22
A celebration!

In September 2018, co-founders Brett Langenberg and Karen Lindsay published the first issue of Futurum magazine. Five years on, and with 22 issues in the Futurum library, we look back and celebrate the milestones that have contributed to Futurum Careers' ongoing success (p 64).

We also celebrate the amazing researchers we have worked with over the past five years – and the students and teachers who are using Futurum resources in classrooms around the world. Futurum is about people and the inspiring learning community we all contribute to.

While studying for his degree in industrial design, Anthony Camu (p 04) was conducting an ethnographic study at London Waterloo train station. In the midst of the busy, commuter-filled station, Anthony watched as a member of staff guided a visually impaired person through the bustling concourse. Inspired by what he had seen, Anthony designed Theia, a handheld orientation and mobility device for blind and partially sighted people.

The Amgen Foundation (p 34) is committed to advancing excellence in science education. President Scott Heimlich explains, "We need to support more people to understand and appreciate the role of science and biotech in our lives." Scott is a firm believer that "everyone needs science, and science needs everyone", and education is key.

As we celebrate Futurum Careers and the wonderful contributors in this issue and issues past, we look forward to continuing our work in supporting education around the world – helping researchers to inspire, teachers to motivate and students to aspire...

THE FUTURUM TEAM

Karen Lindsay
Director

Erica Morgan
Editor

Isla Foffa
Assistant Editor

Sophia Kerby
Senior Graphic Designer

Brett Langenberg
Director

Chris Dowell
Project Manager

OUR WRITERS

Jacob Ashton, MA

Joe Aslett, MSc

Kate Wilkinson, MA

PUBLISHED BY SCI-COMM CONSULTING

A limited company registered in England.
Company No: 10791252

CONTACT

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

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

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

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

SOCIALS

@FUTURUMCareers @Futurumcareers Futurum Careers @futurumcareers Futurum Careers

CONTENTS

Research articles

24

Research articles

INTERVIEWS

COVER STORY
Anthony Camu

04

How to be an inventor and entrepreneur

ANTHONY CAMU

26-year-old **Anthony Camu** has been awarded the Innovate UK's Young Innovators Award for **Theia**, a handheld orientation and mobility device for blind and partially sighted people. He talks us through his entrepreneurial journey, from the conception and development of the device at Loughborough University to founding his start-up Theia Robotics.

Why did you study industrial design and technology at Loughborough University?

I chose to study industrial design because it has elements of art and creativity, whilst also focusing on mechanics, electronics, software, manufacturing, economics and management. Designers, in my opinion, are generalists; we work with engineers, scientists and marketers to integrate technology into useful and desirable products. I've always been a creative and engineering-minded person.

I chose Loughborough because it is a top design and engineering university in the UK. Its facilities are amazing, which include advanced 3D printing technologies and fabrication labs, not to mention the great lecturers and technical staff.

Throughout your degree, you worked for various companies. Why was this important to you?

I worked as a Junior Mechanical Engineer at Mornflake, a cereal production company in Cheshire. Most of my peers at Loughborough went to work for design consultancies, but I was veering towards the engineering side of design and I wanted to explore this further by trying an engineering-heavy job. I spent a year designing specialised components for cereal production machines and configuring assembly lines. It may sound boring to some, but I was inspired by the TV programmes *Inside the Factory* and *How it's made*, both of which feature tours of factories and cover how everyday items are manufactured on massive scales.

Theia, a portable and concealable handheld device that guides users through outdoor environments with little user input. © Anthony Camu

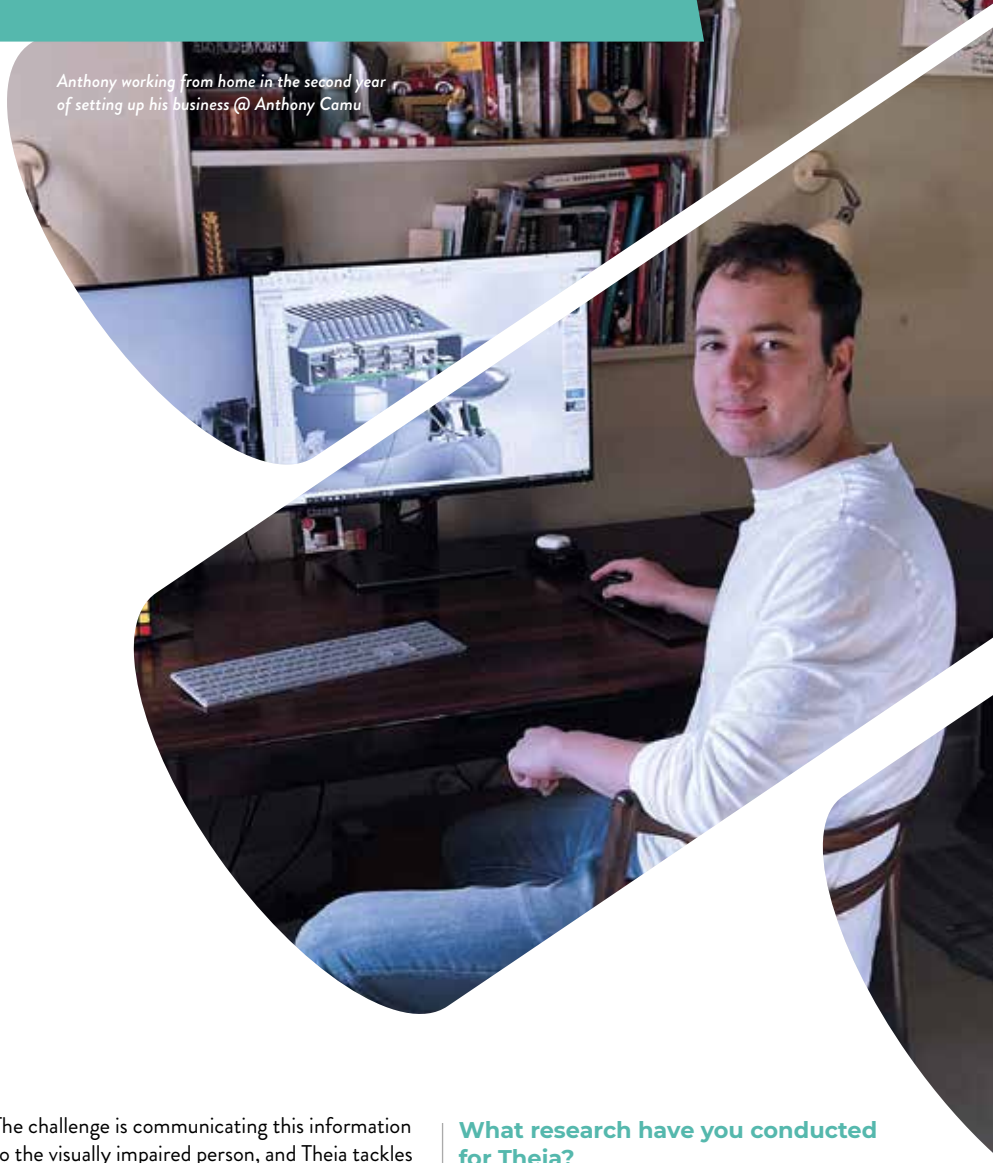
I worked on lots of interesting projects – much of the cereal you find on supermarket shelves have come from the machines I worked on. The role was important to me as it was a real-world engineering experience.

How did you come up with the idea for a handheld navigation device for blind and partially sighted people?

I'm not visually impaired nor did I know many visually impaired people before I started this project, but the inspiration behind Theia came from observing everyday life. I was doing an ethnographic study for a completely different project at London Waterloo Station, and I noticed a blind person who was walking with a white cane and was supported by a member of station staff. They were walking straight through the bustling station concourse, parting the crowd of people, with the blind person tightly holding on to the staff member's elbow. The cane was suspended above the ground by a couple centimetres and, contrary to how I presumed canes were used, was not being scanned from side to side. I drew so many questions from observing this; for example, why was the cane still required if the blind person was being guided by a sighted person?

Why is a cane still required?

The cane is there to prevent the user from tripping over an obstacle, but what's less discernible is the bottleneck of information



Anthony working from home in the second year of setting up his business @ Anthony Camu

transfer between the staff member, the environment and the blind person. Take for example, tiny cracks or lips in pavements, which are everywhere and can trip a partially sighted and blind person up. The person (or guide dog) guiding the visually impaired person may automatically avoid these minute obstacles and not communicate that they're doing so, hence the fear of tripping and/or the blind person's lack of full trust in their guide. A cane provides a physical connection with the ground, allowing users to 'feel' the pavement they're about to walk on. This is probably why canes have hardly changed over thousands of years and are still used today. It's our mission to change that.

Why did you call your device Theia?

Theia is the Greek goddess of sight and light. Theia is also the name of an ancient planet in the solar system that collided with Earth, forming the Moon.

How does Theia work?

Inspired by autonomous vehicles, Theia aims to translate that sense of effortless driving into a system of effortless walking, helping users make complex manoeuvres without needing to see nor think too hard about what they are doing.

Theia is a handheld device which users hold in front of them, similar in size to a TV remote or supermarket scanner. Much like a self-driving car, Theia will programme routes to reach destinations and helps users avoid accidents along the way. Users input where they want to go by voice command, and powerful on-board processors will then determine the best path for the them to take and separate routes into individual commands – for example, bear left at 1.4 m/s.

The challenge is communicating this information to the visually impaired person, and Theia tackles this by physically 'leading' users. Using a special mechanism we developed, users are guided with a unique form of force-feedback. This provides a 'leading' sensation that can be compared to a guide dog's brace, i.e. users holding Theia are able to feel all the subtleties of speed and direction, and the feel of being 'pulled' along.

What research have you conducted for Theia?

We investigated which of the seven human senses are the most useful for walking. Our findings revealed that sight is not the most important sense, neither is hearing nor touch. Proprioception (body position) is more important, followed by the vestibular sense (movement), then sight, hearing, touch, smell and taste. Proprioception tells us

> **"Theia is the Greek goddess of sight and light. Theia is also the name of an ancient planet in the solar system that collided with Earth, forming the Moon."**

School of Design and Creative Arts
© Loughborough University

> **When you start a business, you have to get your hands dirty and expect to burn the midnight oil a lot of the time!**

where our limbs are in space and how to control them without looking at them, and the vestibular sense, also known as the balance sense, helps us move smoothly.

Horse riders, for example, can accurately control the speed and direction of their horses by pulling reigns and moving their legs, etc. I've heard that it's possible for horse riders to ride blind horses once there's enough confidence and trust instilled in the horse. It's a very similar situation with visually impaired people. A person or dog can intuitively guide a blind person by manipulating their proprioceptive and vestibular senses simply by 'pulling' them along a path. The first steps in Theia's creation were focused on developing a new branch of research focused on haptic interfaces, alongside human and robot cooperation. Haptics are about creating an experience of touch for the user by applying forces, vibrations or motions.

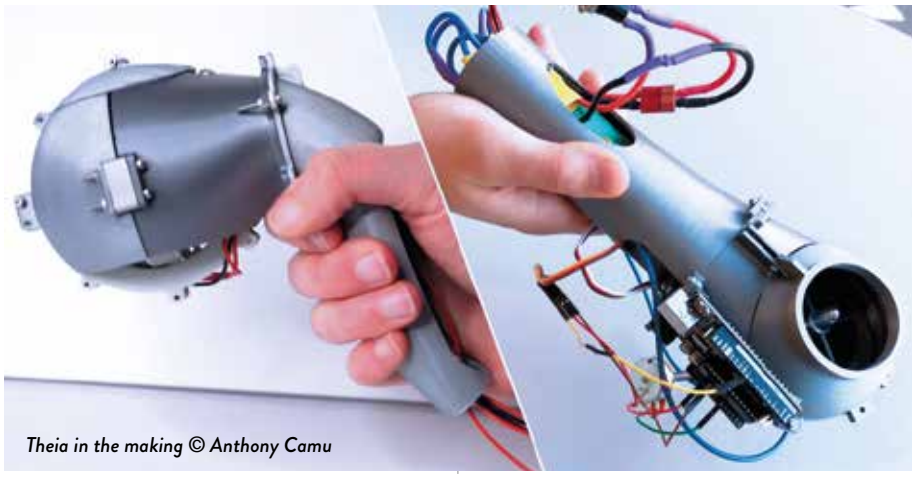
What technical challenges did you have to overcome?

Creating a lightweight, handheld device that provides users with safe, autonomous navigation on pavements is undoubtedly complicated. For example, self-driving cars have briefcase-sized computers, draw a lot of power and are still in the research stage. We've spent a lot of time developing a pedestrian-centred and miniaturised autonomous system, which users can rely on.

At what stage is this device?

We've tested our prototypes with visually impaired participants, both guide dog users and cane users, and we're about one year away from selling our first product. It's important to mention that there is a distinction between guide dog users and cane users, not least between each visually impaired individual. Each person's environment, experiences, and orientation and mobility skills vary.

Inside the School of Design and Creative Arts © Loughborough University



Theia in the making © Anthony Camu

What have been some of your findings during this testing phase?

By working directly with mobility instructors and blind people, we discovered a fascinating partnership between guide dogs and their owners. In fact, their interdependence has been the driving force behind Theia's features. This may also be why guide dog users found Theia, at least initially, more intuitive than cane users. Nonetheless, it was clear we had invented something that requires new skills. That said, within about 20 minutes of using the

Anthony with his current team © Anthony Camu

device, test participants became proficient enough to walk at nearly double the pace of traditional cane users, which is very exciting!

What is Theia's unique selling point?

While improvements in the walking pace are great, it's more about cost and functionality. Many more visually impaired people will be able to get the support and enhanced mobility that would ordinarily come with guide dogs but without the long waiting lists and high costs.

What led to you founding Theia Robotics?

Theia Robotics started out as a university project. Loughborough University's public relations department and I wrote a press release about Theia which piqued the interest of PA media, a news agency. The next morning, I was on BBC Breakfast (a daily morning TV programme in the UK) talking about Theia to 7.7 million people! I then appeared on *The Gadget Show*, followed by J-Wave, Tokyo's largest radio station. I was also featured in UK newspapers, such as the *Daily Mail* and the *i Newspaper*. This unexpected media attention led to hundreds of visually impaired people reaching out to me wanting to buy a Theia, although, at the time, the project was still in its infancy. So, I decided to dedicate the next few years towards making Theia a reality by starting a company and building a team. From a very young age, I'd wanted to found a company.

How challenging is it to set up your own company?

I started Theia Robotics fresh out of university, and it's fair to say I didn't have a clue how to start a business! In the first year, I joined programmes such as Loughborough University's incubator, LU Inc., to learn about entrepreneurship and business operations. As a sole founder, I wear many hats, including designer, engineer, manager, accountant, administrator, employer, salesman and cleaner, etc. When you start a business, you have to get your hands dirty and expect to burn the midnight oil a lot of the time!

I made quite a few mistakes when I started out, but I had the support of advisors and, eventually, investors whom I met by growing my network, for example on LinkedIn, and from the programmes I had joined. A great programme was Innovate UK's Young Innovators programme. It provides tailored business support, as well as advisors and an initial injection of capital (money). After three years of running a start-up, I can say the biggest challenge for any company is cash flow. If you start a business, it's important to know about budgeting and forecasting – Excel is a good friend!

What is your proudest moment to date?

My proudest moment was when I was standing on a train platform in Wolverhampton last year, and I received an email from Innovate UK notifying me that my company had been awarded a SMART grant. It's a very competitive grant which provided

> ***"Loughborough University's PR department and I wrote a press release about Theia, which piqued the interest of PA media. The next morning, I was on BBC Breakfast talking about Theia to 7.7 million people! I then appeared on The Gadget Show, followed by J-Wave, Tokyo's largest radio station."***

the funds I needed to hire my first staff members and move into an office in London. Before receiving the grant, I was working from a shed in my parent's garden for two years.

What is your philosophy in life that helps drive you forward?

Persistence is key! I have also always wanted to be doing something that widens the skills I'm passionate about. I never stop learning.

What is one piece of advice you wish someone had given you at the beginning of your career?

As a young entrepreneur, my career path has been a bit unconventional. When you start a business, you're the boss, and you work things out as you go along. Ideally, I would have liked to have had a few more years' experience working for someone else before starting a company. That said, I felt it was important to start a company straight away because of the media interest and the need to get a patent. Although I'm very happy where I am, if I could go back, I would probably study a part-time engineering master's degree at the same time as starting my business. Also, if I were to work for someone else, I would work for a start-up with less than 50 employees in an industry I'd want to work in. But hindsight is a beautiful thing!

A close-up of Theia © Anthony Camu

Connect with Anthony

anthony-camu
theia-guidance-systems/about

Can we engineer bacteria to regenerate tissues?

Dr Christopher Contag, a biomedical engineer and microbiologist at **Michigan State University** in the US, is creating engineered endosymbionts – bacterial cells that can be delivered into cells of other organisms where they can persist and control cellular functions. Since these engineered endosymbionts have the potential to guide the regeneration of our organs and tissues, Chris hopes his work will help to rebuild tissues in patients with damaged or diseased organs.

Dr Christopher Contag

Institute for Quantitative Health Science and Engineering, Colleges of Engineering and Human Medicine, Michigan State University, USA

PROFILE

Fields of research
Biomedical Engineering, Endosymbiont Engineering, Medical Imaging, Microbiology

Research project
Developing engineered endosymbionts that can repair tissues in the body

Funders
US National Science Foundation (NSF), National Institutes of Health (NIH)

Talk like a ... biomedical engineer

Cytoplasm — the liquid in a cell

Endosymbiont — a symbiont that lives inside the cell of a different species

Eukaryote — an organism with cells containing a nucleus and other organelles, e.g., a plant or animal

Genome — the complete set of genetic material in an organism

Host cell — the cell in which an endosymbiont lives

Macrophage — an immune cell responsible for removing infectious agents from an organism and rebuilding tissues

Organelle — a structure with a lipid membrane within a eukaryotic cell, including mitochondria (where respiration occurs) and chloroplasts (where photosynthesis occurs)

Prokaryote — a relatively simple single-celled organism that does not contain a nucleus or organelles, e.g., a bacterium

Stem cell — a non-specialised cell that can differentiate into (become) a specialised cell

Symbiont — an organism that lives in symbiosis with another species

Symbiosis — a close biological relationship between organisms of different species

Tissue — a group of eukaryotic cells that work together to perform a specific function, e.g., liver tissue, heart tissue or lung tissue

If one of your organs fails or becomes damaged, the best option may be to replace it with an organ donated by someone else. However, while organ transplants are life-changing for many patients, they are also expensive, risky and in extremely high demand. At any one time in the US, about 100,000 people are on the waiting list for organ donations. If you need a new heart or lung, you will have to wait about four months, while the average waiting time for a donated kidney is five years.

"There is a need to develop new tools to repair or replace damaged organs and tissues," says Dr Christopher Contag, a biomedical engineer and microbiologist at Michigan State University. "If this could be done inside the body, it would avoid some of the risks and costs of organ transplantation and remove the need for donated organs." Such tools could be used broadly across many organ systems, for example, to repair damaged heart tissue after a heart attack or regrow neurons to reverse the effects of Parkinson's disease. "We propose to create engineered endosymbionts that can reprogram cells to become stem cells that, with the flip of a genetic switch in the endosymbiont, can activate a pathway to turn that stem cell into a specific tissue cell, such as a heart cell, liver cell or neuron," explains Chris. "We could then direct cells in the body to repair or replace damaged tissues, while controlling them from outside the body."

While this may sound like the work of science fiction, Chris believes it could become a reality that revolutionises medicine. He has established this new scientific field of endosymbiont engineering for human health in the hope of improving health outcomes for patients with damaged and diseased tissues.

What is an endosymbiont?

Symbiosis is a close biological relationship between two organisms of different species (known as symbionts). For example, the lichen you might see growing on trees or tombstones is not a single organism, but a symbiotic relationship between algae and fungi. The algae provide nutrients for both organisms through photosynthesis, while the fungi provide support and shelter.

Chris works in the lab with his colleague, Dr Victoria Toomajian

An endosymbiont is a symbiont that lives inside a cell of another species (known as the host cell). "Evolution used the process of endosymbiosis to create eukaryotes," explains Chris. The endosymbiont theory states that eukaryotic cells evolved when one prokaryotic cell engulfed another, then the two cells co-evolved with one prokaryote existing as an endosymbiont within the other. Over about two billion years, the genomes and biologies of the two prokaryotic species became interdependent and were optimised to live harmoniously together. The endosymbionts evolved into organelles, such as mitochondria and chloroplasts, resulting in eukaryotic cells. "Engineered endosymbionts are bacterial cells that have been artificially engineered to create synthetic symbiotic relationships, so they exist as a cell living inside a cell of another species," explains Chris.

How does Chris create and control engineered endosymbionts?

"We started the field of endosymbiont engineering with the idea that we could replicate the evolutionary process of endosymbiosis in the laboratory," explains Chris. "We hope to create new endosymbiotic relationships, where the engineered endosymbionts are designed and built to control the biological processes of the cell in which it lives." These engineered endosymbionts are bacterial cells that are usually free-living prokaryotes, but have been artificially modified so they can exist as synthetic organelles in the cytoplasm of mammalian host cells.

To create an engineered endosymbiont, Chris and his team genetically modify innocuous (harmless) bacteria of various species. They add genes encoding eukaryotic functions that interact with the host cell. The team will then reduce the endosymbiont's genome to its minimal size and modify it so it is more compatible with the mammalian host cell. "We also build biological indicator lights, based on luminescing and fluorescing proteins, into either the host cell or the bacterial endosymbiont," says Chris. "This lets us locate the endosymbionts in the body and monitor whether the engineered genes are 'on' or 'off'. It also helps us determine whether the system is working, much like the warning lights in a car that indicate whether something is functioning or not."

> ***"Controlling tissue regeneration from outside the body still seems like science fiction to many people."***

The overall goal is to link the biology of the bacterial and mammalian cells so scientists can control the function of the host cell by controlling the endosymbiont. It is important that the endosymbiont genes can be controlled in a way that does not interfere with the biochemical processes happening in the mammalian host cell. To achieve this, the team controls the endosymbiont genes using either sugars that mammalian cells do not use, heat produced by lasers, ultrasound or alternating magnetic fields.

Can we use these engineered endosymbionts for medical purposes?

While Chris and his colleagues have had many successes developing their engineered endosymbionts, it will be a while before they are used in medicine to direct the regrowth of hearts and kidneys. So far, the team has successfully used engineered endosymbionts to reprogram macrophages in the body to build new tissues, instead of fulfilling their alternate function of removing pathogens or dead cells. However, this has not been easy. Some of the main challenges faced by the team are encouraging the host cells to accept the engineered endosymbionts and encouraging the endosymbionts to better tolerate the host cells. "Mammalian cells have evolved many mechanisms to eliminate bacterial cells, even engineered ones, from their cytoplasm," says Chris. "We need to overcome these mechanisms before we can create true symbiotic relationships between the host cell and engineered endosymbiont."

This will be key to increasing the length of time that the endosymbionts persist in the host cells before they are rejected. At present, engineered endosymbionts can persist for a few days in a mammalian host cell, but it may take weeks or months to rebuild tissues. "We also want to introduce endosymbionts into a range of different cell types," Chris says, "and we want to demonstrate that engineered endosymbionts can reprogram cells to become stem cells."

This last step will be essential if engineered endosymbionts are to be used for tissue regeneration. Chris hopes to insert genes into the endosymbionts that reprogram mammalian host cells into stem cells. If these stem cells can be controlled by the endosymbionts, which, in turn, are being controlled from outside the body, then scientists could program cells inside the body to rebuild and repair damaged tissues, by instructing the stem cells to become whatever type of cell is necessary.

"Controlling tissue regeneration from outside the body still seems like science fiction to many people," says Chris. This is both an achievement and a challenge when it comes to the team's research. On the one hand, it shows just how innovative and cutting-edge these ideas are, highlighting how Chris is pushing the boundaries of scientific understanding and possibilities. On the other hand, some scientists remain sceptical about the realities of inserting bacteria into people to repair their organs. However, bacteriotherapy (which uses bacteria to kill tumours) has become standard treatment for bladder cancer and is now being investigated to treat a variety of other cancers. "We can build on these successes if we are methodical and transparent in our designs to ensure that the scientific community accepts this novel approach to guiding tissue regeneration," says Chris.

With further advances in the field of endosymbiont engineering, these bacteria may one day be able to regrow damaged human tissues, eliminating the need for organ transplants.

About *biomedical engineering*

Biomedical engineering lies at the intersection of biology and engineering, while also drawing on knowledge from medicine and chemistry. While some biomedical engineers create mechanical or electronic devices for medical use, such as pacemakers and prosthetic limbs, others, like Chris, apply engineering techniques to biological systems, for purposes such as gene therapy, gene editing and tissue engineering. "Biomedical engineering is a broad field that can impact everything from food production to space exploration," says Chris. "In this field, your primary limitation is your ability, or inability, to imagine the future!"

The importance of futuristic thinking

When Chris realised that the challenges of organ donation and transplantation could be solved by regrowing tissues in the body, he began to investigate the possibility of engineering synthetic endosymbionts. In doing so, he established a new subfield of biomedical engineering. And, while some view his work as science fiction, Chris has proven that the concepts behind his ideas are theoretically and practically possible.

As technology and biological understanding advance, great progress can be expected in all fields of biomedical engineering. "In the field of endosymbiont engineering, I think we will develop bacteria that only contain the minimal number of genes needed for their growth, and we will generate libraries of genes that drive the development of different cells and tissues," predicts Chris. "With this, we could customise the minimal genome bacteria by inserting other genes, so the bacteria perform different functions. For example, after a heart attack, a patient could be prescribed a minimal genome bacterium with heart generating genes that would guide the patient's heart cells to regenerate."

Progress in biomedical engineering relies on the next generation of scientists having a futuristic mindset and a willingness to pursue the unknown. As the chemist, Frank Westheimer, once said, "Progress is made by young scientists who carry out experiments that old scientists said wouldn't work." Chris acknowledges that some scientists call his work 'science fiction', in part due to a fear of the unknown. "Science fiction writers ask, 'What if?'," he says. "As scientists, we think of what might be possible and ask, 'What's the next step?' We begin with the end in mind and direct our experiments toward this goal. However, innovations lie in the unexpected results, and therefore we must go into every design and experiment with our eyes wide open to appreciate the unexpected and then explain it."

Pathway from school to *biomedical engineering*

- "All engineering fields require math," says Chris. "So, get a solid education in math and quantitative sciences." Study mathematics, biology, chemistry and physics and, if your school offers classes in engineering and computing, take them as well, since these subjects will also be useful.
- Some universities offer degrees in biomedical engineering, bioengineering or biological engineering. Related degrees in biochemistry, biology or other engineering fields (e.g., mechanical or electrical) could also lead to a career in biomedical engineering.

Explore careers in *biomedical engineering*

- "The Biomedical Engineering Society (BMES; **www.bmes.org**) and the Engineering in Medicine and Biology Society (EMBS; **www.embs.org**) are outstanding organisations to get involved with," says Chris. Both societies have a wealth of resources, including podcasts and informative videos on topics such as 'Is biomedical engineering right for you?' and 'Career paths in biomedical engineering'.
- The US Bureau of Labour Statistics has detailed information about careers in bioengineering and biomedical engineering, including what the roles involve, the skills and qualifications you will need and the salary you can expect: **www.bls.gov/ooh/architecture-and-engineering/biomedical-engineers.htm**
- In this video from the American Society of Mechanical Engineers, bioengineers discuss what work in the field involves: **www.asme.org/topics-resources/content/video-bioengineering**

© Gorodenkoff/Shutterstock.com

Meet *Chris*

As far back as I can remember, I wanted to be a scientist. I was always fascinated by the processes of biology – while my friends were building model cars, I was building models of the human eye, ear and other organ systems! I saw the interconnections of biological systems while picking edible plants with my dad and spending days wandering and camping in the woods.

My father and grandfather were veterinarians and, while growing up, I spent many hours in their lab. My dad inspired curiosity in me as we grew bacteria, hatched turtle eggs, did chemistry experiments, blew glass bottles and treated sick animals that I found in the woods, from dogs and cats to squirrels, snakes and a mountain lion (though I didn't bring the mountain lion back to the clinic!).

When I was a kid, there was a science fiction TV show called *'The Time Tunnel'*, about scientists who build a time tunnel and adventurers who travel through it. My brother wanted to be one of the heroic time travellers, but I wanted to be the chief scientist and figure out how the scientists could save the day. I still believe that scientists will save the day by developing innovative new technologies for addressing climate change and improving human health.

I was extremely lucky to have teachers who curated curiosity in their students. When I was 10, we were learning about eyes by looking at drawings in books. I didn't think this was sufficient, so I asked my teacher if I could bring an eye to school to dissect in class. I don't think she realised I was serious, because she just said, "Sure". So later that week, when I helped my dad deliver a still-born calf, we removed its eye and the next day I took the eye, a dissection tray and the proper tools to school and offered them to my teacher. I still remember the expression on her face as she stepped back, and said, "Why don't you teach today?" So, I led the class through the dissection of the calf eye. It wasn't until many years later that I realised this might have seemed strange! To me, I was just bringing my everyday life into the classroom.

I never get tired of watching biology in action – from the molecular and cellular level while working in the lab, to the organismal and ecosystem level outside in nature. Whether in the lab, mountains or oceans, there are so many aspects of biology to observe and wonder about.

Chris' *top tips*

1. Instead of 'thinking outside the box', just 'think outside, no box required'. It is human nature to categorise and catalogue things, but every time we box something in, we eliminate opportunities.

2. Follow your passion, not the career with the highest salary or most manageable work week. To be happy, make your work your hobby and your hobby your work, by integrating your life and work so that what you accomplish in each area exceeds your and others' expectations.

3. Never let your mind grow old – keep the youthful wonder alive. I like to think of myself as a young scientific mind in an old human body! I never want to be a scientist who says 'no' to trying something new.

A world of opportunity in dental research

Oral health plays an integral part in our overall health. However, oral diseases are prevalent worldwide, and health inequities mean that not everyone has access to the oral healthcare they need. Dental researchers are tackling these challenges and, as **Dr Jennifer Webster-Cyriaque**, Deputy Director of the **National Institute of Dental and Craniofacial Research** in the US, explains, the opportunities for the next generation of dental researchers to contribute to this vital field are wide and varied. The National Institute of Dental and Craniofacial Research (NIDCR) is one of 27 Institutes and Centers of the National Institutes of Health (NIH).

Dr Jennifer Webster-Cyriaque

Deputy Director, National Institute of Dental and Craniofacial Research, National Institutes of Health, Maryland, USA

Fields of research
Oral Health, Microbiology, Immunology, Virology

Funder
National Institute of Dental and Craniofacial Research, National Institutes of Health (NIDCR/NIH)

PROFILE

Talk like a ...
dental researcher

Artificial intelligence (AI) — the ability of a computer to perform tasks usually only possible for a human

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

Big data — data sets so large they require a computer to analyse them

Biofilm — a thin layer of microbial cells

Caries — tooth decay, also known as cavities

Cleft lip — a condition where the parts of the upper lip do not join together, and there is a gap

Cleft palate — an opening or split in the palate (the roof of the mouth)

Genetics — the scientific study of genes

Health inequality — the differences in heath between different groups of people

Human immunodeficiency virus (HIV) — a condition where the body's immune system is unable to fight off infection or disease

Idiopathic — where the cause is unknown

Nanoparticle — an incredibly small particle, between 1 and 100 nanometres in diameter

Salivary gland — the organ that produces saliva (keeping your mouth moist and aiding digestion)

Socio-economic — related to social and economic factors

Systemic disease — a disease that affects the whole bodily system

When you think of dentistry, you might have memories of going to the dentist when you were younger, lying back in that dentist's chair, saying 'Ahh', rinsing your mouth with that distinctive pink liquid and receiving your 'smile' sticker for your cooperation. If you are a conscientious teeth brusher, thoughts of your daily cleaning routine, mouthwash and interdental brushes might spring to mind. However, when you think of dentistry, do you ever consider health inequalities, microbial biofilms, genetics or diseases such as HIV?

There is so much more to our oral health than a bright smile and much more to careers in dentistry and dental research than cleaning people's teeth. As Dr Jennifer Webster-Cyriaque, Deputy Director of the National Institute of Dental and Craniofacial Research, says, "Oral health is important because without it, we cannot be truly healthy." Researchers across the dental field are conducting research that aims to ensure just that – that everyone, regardless of background and social-economic position, can have good oral health and optimal overall health.

Oral health can be seen as a 'barometer' for the rest of the body, signalling health issues that might otherwise go undiagnosed. The impact of many systematic diseases manifest in our oral health. "For example, the saliva is a wonderful diagnostic tool. It can inform us about many systemic processes, is readily available and its collection is painless," explains Jennifer. Equally, oral diseases can affect other parts of our bodies, leading to illness.

Though many of us do our best to keep our mouths and teeth clean and healthy, oral diseases are a significant issue for society. "Oral diseases are highly prevalent, with 90% of people in the world affected by oral disease, including caries, gum disease, cancers, genetic disorders (including cleft lip and palate), and

> ***Working in dental research is incredibly rewarding, and we look forward to you joining us!***

autoimmune diseases," says Jennifer. There is clearly work to be done – both for scientists to research and understand how to help people, and for the general population to understand how to look after their oral health and, as a consequence, their overall health. "Dental research focused on understanding how best to prevent oral disease and on understanding the relationship between oral disease and systemic disorders will lead to significant improvement," says Jennifer.

With this in mind, Jennifer is passionate about what the next generation of dental researchers could achieve. "There are so many research opportunities in dental research as the unknowns abound," she says. There are challenges to overcome but also many advancements to build upon. "For example, artificial intelligence is being used to diagnose oral cancers, while microbots made of nanoparticles are being used to brush and floss teeth," explains Jennifer.

It is a fascinating time to be entering the world of dental research, where data science and computational tools are being used to look at 'big data', answering important questions in oral health. "New technologies are supporting dental researchers in their work," says Jennifer. "More people will keep their teeth, have viable replacement teeth and benefit from a healthy oral environment. Working in dental research is incredibly rewarding, and we look forward to you joining us!"

Jennifer's *career*

I was fortunate to have opportunities to do both undergraduate and dental school research in minority-targeted research training programmes. As a dental student, I recognised there were many oral maladies that were characterised as idiopathic. I reasoned early on that it would be difficult to treat disease without an understanding of cause. Research was the critical tool to help with understanding oral disease in a medically complex patient population, like the one that I saw.

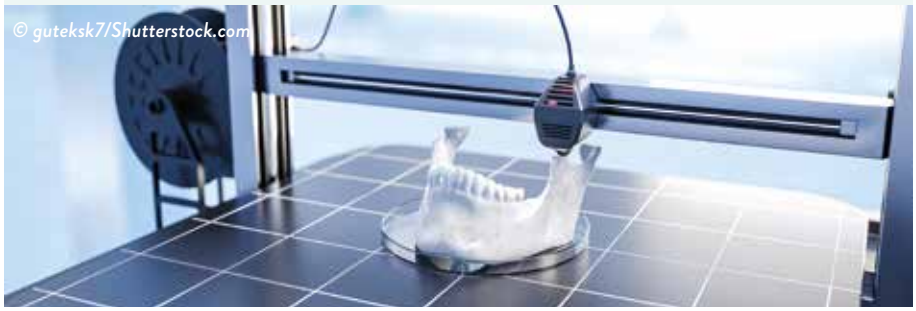
Throughout my training, I have been the beneficiary of wonderful mentorship that has been critical to shaping my career.

I have experienced multiple eureka moments in my career. Among them were the findings that Kaposi's sarcoma Herpesvirus (an infection linked to several cancers) was an oral pathogen, that a salivary gland disease that occurs in persons with HIV was associated with a polyomavirus and could be targeted therapeutically, that treating oral conditions could improve systemic outcomes in HIV, and that bacteria could drive viral infections and virus driven cancers.

I am proud when I see my students and trainees reach their aspirations, becoming dentists, achieving tenure, or becoming professors and deans of universities. Being elected to the National Academy of Medicine, being selected to NIDCR leadership, and being among the first to demonstrate that cancers in people who didn't smoke or drink were associated with HPV have also brought me much satisfaction. Being involved with oral health care in Malawi and with the implementation of the first dental school in that country was also highly rewarding.

Jennifer's *top tip*

Wanting to know the answer is the critical first step toward becoming a researcher and scientist.



Meet *Donald*

Dr Donald L. Chi

Professor and Associate Dean for Research, Lloyd and Kay Chapman Endowed Chair for Oral Health, School of Dentistry, University of Washington, USA

Fields of research
Paediatric Dentistry, Health Services

Funders
NIDCR, WA State Dept of Health, CareQuest, Health Resources and Services Administration

Glossary

Fluoride — a mineral used in dental care products, such as toothpaste and mouthwash

Health disparity — preventable difference in healthcare

Marginalised communities — groups of people that may be cut off from certain elements of society or who lack power and agency, often due to race, socio-economic status or physical, intellectual or developmental disability

Paediatric — relating to children's healthcare

Socio-economic — related to social and economic factors

Donald is a paediatric dentist whose research addresses health disparities. He works with vulnerable and marginalised communities, targeting health inequality.

I work with low-income, socio-economically disadvantaged populations (e.g., those insured by Medicaid, which is healthcare provided by the state); minoritised subgroups (e.g., Alaska Native children, older adults of Korean or Latino/Hispanic descent); and medically compromised groups (e.g., individuals with cystic fibrosis, autism, intellectual and/or developmental disabilities, or other special healthcare needs). Many individuals from these vulnerable communities have similar experiences. These include difficulties accessing dental care, high sugar diets, and inadequate fluoride exposure – all of which pose risks for their oral health.

Children in these communities can face several problems with their oral health. Oral health inequities in childhood can lead to pain, missing teeth, hospitalisations, systemic diseases and missed school days. All of these factors have lifelong consequences, many of which are irreversible.

As dental researchers, we can help to generate new knowledge that can be used to develop interventions and policies aimed at promoting optimal oral health behaviours, making children and adults healthier.

Social and behavioural sciences are a central part of my research. My research shows that the social determinants of oral health matter; however, they are difficult to change through interventions. This is where all-important policies come into play.

> ***"Conducting research that has a positive impact on vulnerable families is something I am very proud of."***

An example of a success I've had in research is our work in Alaska Native communities, which is a culmination of many years of collaboration over time. We spent over six years co-developing an intervention to address sugared fruit drinks and applying for research funding. In 2018, we received an NIH grant that provided the resources needed to finalise the intervention. We worked hard to have everything ready to go in 2020 and then the COVID-19 pandemic hit. Though delayed, we were able to launch the intervention in September 2022, and we are currently completing data collection. I consider this project a success because of the deep, trust-centred partnerships that defined our relationships with the study communities, which allowed us to get through the acute phase of the pandemic and implement a programme we felt was an important step in addressing a public health challenge. I'm excited about the next steps.

It's an absolute joy working with children though paediatric dentistry. One of the challenges in paediatric dentistry is that many high-risk children will continue to come back to the office with cavities, even after you spend a lot of time and effort to fix them. This means that alternative approaches are needed for these children to help them avoid the recurring cycle of dental disease. This is where dental research comes into play – my research is aimed at breaking the disease cycle. Conducting research that has a positive impact on vulnerable families is something I am very proud of.

A career in paediatric dentistry summed up in one word? Opportunities.

© santypan/Shutterstock.com

Donald's *top tip*

Hone your thinking and writing skills, read broadly, and when communicating with others, practise conveying the big picture first.

Meet *Margherita*

Dr Margherita R. Fontana

Clifford Nelson Endowed Professor and Professor of Dentistry Director, Global Initiatives Program in Oral and Craniofacial Health, Department of Cariology, Restorative Sciences & Endodontics, University of Michigan School of Dentistry, USA

Field of research
Cariology

Funders
Federal (e.g., NIH, CMS), Industry, Foundations

Glossary

Biofilm — a thin layer of microbial cells

Caries — tooth decay, also known as cavities

Cariology — the scientific study of caries and its treatments

Health equity — when everyone has the same opportunities to achieve optimal health

In vitro — occurring in controlled environments, such as test tubes or petri dishes

As a cariologist, Margherita researches tooth decay. Currently, she is conducting clinical studies to investigate caries risk in young children.

I pursued clinical research to understand how we can improve health and well-being and reduce health disparities. It is essential to look at information and test products and strategies directly with humans, including as diverse a group as possible, so that findings from clinical research can be applicable to everyone. Clinical research is vital for our understanding and treatment of diseases, and for achieving health equity.

We know that the risk of getting cavities as a child can be predicted from as early as aged one, before children have many teeth. Questions that a parent can easily answer during medical paediatric visits early in their child's life can help determine the risk of their child of getting cavities years later. This offers an opportunity for parent and medical and dental providers to target preventive interventions to those at higher risk, with the goal of keeping children healthy as they grow.

We have developed caries risk tools for early childhood and are now focusing on the school age years into early adolescence. We are interested in finding out not only the risk of developing future cavities in order to prevent them, but the path to getting cavities (e.g., where will the cavities develop, and how fast in the future). We are also looking at how oral risk factors interplay with other health related behaviours, and the development of these behaviours over childhood. This will help us understand where we may be able to intervene more cost-effectively to decrease risk and improve patient-related outcomes, and opportunities for interprofessional collaboration in health management.

> ***"I have seen our work impact policies to improve health, and I have seen the direct positive impact on families."***

We are conducting in vitro studies of biofilms. Chemical and biofilms caries models are important to understand how biofilms react with tooth surfaces and how cavities develop in response to different conditions. We can also test the impact of potential treatment agents, to help us identify promising ones to be later tested in clinical studies and, eventually, made available to the public.

A career in cariology relies on many years of study, but it is very rewarding. I have been able to work and collaborate with wonderful communities of people in different parts of the world, all committed to improving the health of children worldwide. I have seen our work impact policies to improve health, and I have seen the direct positive impact on families.

What one word sums up a career in cariology? Impactful.

Margherita's *top tip*

Follow your dreams and take advantage of opportunities as they happen in life.

Explore careers in *dental research*

- Donald suggests finding a dentist to shadow. This could be a dentist who runs a full-time practice or a dentist in an academic setting. Caroline adds how valuable it is to talk to people in the profession to hear about their work.
- Margherita advises finding great mentors, and joining scientifically strong groups. For example, in her speciality, there is the European Organisation of Caries Research (**orca-caries-research.org**) and the American Academy of Cariology (**aacariology.org**).
- There are many societies to explore:
  - Caroline recommends the American Academy of Oral Medicine (**www.aaom.com**) and the International Association for Dental Research (**www.iadr.org**)
  - Ophir highlights that the American College of Medical Genetics and Genomics (**www.acmg.net**), the American Board of Medical Genetics and Genomics (**www.abmgg.org**) and the American Society of Human Genetics (**www.ashg.org**) all have excellent websites that are worth exploring.
  - Janice mentions the American Cleft Palate-Craniofacial Association (**acpacares.org**) and the Society of Developmental Biology (**www.sdbonline.org**).

Professor Ophir Klein

Professor of Paediatrics, Cedars Sinai, California, USA

Fields of research
Paediatrics, Medical Genetics

Funders
NIH, private foundations, CIRM, TRDRP

Glossary

Genetics — the scientific study of genes

Craniofacial — relating to the cranium (skull) and face

Paediatric — relating to children's healthcare

Phenotypic — relating to the physical characteristics of an organism

Stem cells — unspecialised cells that are used as the 'raw material' to produce specialised cells

Meet *Ophir*

Ophir is a paediatrician and medical geneticist. His research focuses on craniofacial development.

Our lab is generally interested in how organs form in embryos and how they renew and regenerate in the adult. Specifically, we are studying how teeth form and how the lining of the mouth (the oral mucosa) can heal so quickly and without scarring.

To study craniofacial and dental birth defects, we perform a variety of studies, including using mouse and zebrafish animal models, experiments with cells derived from patients, and genetic and phenotypic analyses of the patients themselves. By integrating all of these types of data, we can obtain a fuller understanding of the mechanisms underlying birth defects.

By learning how stem cells are able to fuel both normal turnover of tissues as well as repair of injuries and other types of damage, we are laying a foundation for harnessing the regenerative power of these amazing cells and thinking about how to use them therapeutically. I am very optimistic that stem cells will have a significant impact on healthcare in the long run. We still have a lot to learn, but as we learn more about the remarkable abilities of these cells, it seems very likely that they will become an important part of our therapeutic toolkit.

In medical genetics, there are a lot of 'diagnostic mysteries' – unlike many other areas of medicine, it is not immediately clear what the underlying problem is that is causing the patient's condition. This is often a huge challenge but also what makes the field so interesting and exciting.

The biggest highlight of my career has been the opportunity to work with and mentor so many talented, inspiring young people – it is the most fun part of my job and what gets me up every morning.

I studied Spanish before studying medicine and genetics. I wish I could say that this was all part of a master plan that I developed at a young age! But honestly, I just did what seemed fun and interesting at each point in my career. When I started college, I was fascinated by language and literature and chose to get a degree in Spanish. When I started to work in a lab, I realised that science and medicine were even more exciting to me, so I pivoted to a new field.

What one word sums up a career in medical genetics? Captivating.

Ophir's *top tip*

Medical and scientific training will be difficult and challenging at times, and they'll require some sacrifices, but if you love what you're doing, it is definitely worth it. If you can, try not to worry too much about what is going to happen in the distant future, and focus on the journey.

Pathway from school to *dental research*

- A focus on biology, chemistry and mathematics at school and post-16 years will provide a good foundation for a dental degree.
- Collegedunia provides details about studying dentistry in the US: **www.collegedunia.com/usa/article/dentistry-in-the-us-why-us-deadlines-application-process-and-cost**
- UCAS provides more information about degree entry requirements for the UK: **www.ucas.com/explore/subjects/dentistry**
- There are many opportunities to try dental research with the NIH and at colleges and universities across the US, in low and middle income countries, and elsewhere:
  - This website links to NIH training opportunities from high school and beyond: **www.nidcr.nih.gov/careers-training**
  - The University of Michigan School of Dentistry offers a variety of programmes for people interested in pursuing dentistry: **dent.umich.edu**
  - The University of Iowa's Secondary Student Training Program Courses (SSTP): **catalog.registrar.uiowa.edu/courses/sstp**
  - The Cedars Sinai programmes for students: **www.cedars-sinai.org/community/programs/career-training.html**
- Azeez advises participating in summer experiences at the NIH and genetics labs (**www.nidcr.nih.gov/careers-training/interns-fellows/high-school-college-students**), while Janice recommends the Office of Intramural Training and Education's website for summer internships and other programmes (**www.training.nih.gov/programs/hs-sip**).
- Jennifer highlights the huge range of fields of science that dental research involves: "Genetics, oncology, developmental biology, engineering, neuroscience, microbiology, immunology, biochemistry, physiology, public health, data science/computational biology, clinical research, and health disparities just to name a few...," she says. The discipline that appeals to you will impact the courses you take at university level and the path you take beyond that.

Meet *Darnell*

Darnell leads the Kaigler Research Group, which is focused on the development of methods to regenerate tissue.

Dr Darnell Kaigler

Director of Kaigler Lab, Major M. Ash Collegiate Professor of Dentistry, Department of Periodontics & Oral Medicine, Department of Biomedical Engineering, University of Michigan School of Dentistry, USA

Fields of research
Regenerative Medicine, Stem Cell Biology and Therapy

Funders
Burroughs Welcome Fund, Oral-Maxillofacial Surgery Foundation, NIDCR/NIH

Glossary

Craniofacial — relating to the cranium (skull) and face

Periodontics — the branch of dentistry related to gum disease

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

Stem cells — unspecialised cells that are used as the 'raw material' to produce specialised cells

My lab conducts research on stem cell-based therapies for the regeneration of oral tissues. We are currently trying to determine how stem cells from the body can be procured, cultivated and re-introduced to the body to repair, regenerate and reconstruct diseased and damaged tissues.

Stem cell therapy can enable bone regeneration by turning into bone cells, which ultimately form bone tissue. Our work focuses on understanding how to best direct that process.

Our successes include having conducted clinical trials which have demonstrated that stem cell therapy for regeneration of jawbone and craniofacial bone tissue is safe and effective. Our studies were the first randomised, controlled, clinical trials in the US to show this.

This stem cell therapy could have great impact on people and their everyday lives by enabling treatment of debilitating conditions for which there are currently limited treatment options.

The biggest challenge in my work is being able to maintain a high level of knowledge and clinical skill in periodontics, while also sustaining a productive and innovative research programme.

Using stem cell therapies to successfully treat patients in our clinical trials and seeing the impact it has had on patients are highlights of my career.

What one word sums up a career in periodontics? Awesome.

Dr Azeez Butali

Gilbert Lilly Endowed Professor of Diagnostic Sciences, College of Dentistry, University of Iowa Health Care, USA

Fields of research
Genetics, Genomics and Ethical, Legal and Social Issues (ELSI)

Funders
NIDCR/NIH

Glossary

Anomaly — an abnormality or variation

Craniofacial — relating to the cranium (skull) and face

Epidemiology — the study of patterns and factors in health and diseases

Genetics — the scientific study of genes

Orofacial — relating to the mouth and face

Meet *Azeez*

A researcher in dental and craniofacial genetics, Azeez also directs the African Craniofacial Anomalies Network.

My research has included looking at non-syndromic clefts in populations of African descent. A non-syndromic cleft is a birth defect where the nasal and oral cavities have not divided completely. Approximately 1 in every 2000 live births are affected by the condition.

The African Craniofacial Anomalies Network is a collaboration between scientists in Ghana, Ethiopia, Kenya, Nigeria and Rwanda. We aim to train and build capacity in Africa for research into dental and craniofacial diseases, to investigate the genetics and environmental causes of dental and craniofacial diseases, and to create opportunities for inter and trans-disciplinary and global research. This type of collaboration is important in enabling us to understand the genetic diversity that exists in Africa and how this can help us understand the causes of dental and craniofacial diseases.

In looking at the role of genetics in non-syndromic clefts, my lab has discovered three cleft palate genes and genes for a dental syndrome.

Genetics is a rapidly evolving field, and there is need for constant training and retraining to keep abreast with the dynamic research environment. It requires a close tab on the literature and collaboration with other experts in the field.

I undertook my PhD in genetic epidemiology after obtaining my dental degree to understand the 'why' and 'how' of dental and craniofacial diseases beginning with orofacial clefts.

My career highlights include having successfully established a research team and network that has contributed substantially to dental and craniofacial research through the discovery of three clefting genes and one dental syndrome gene. I have produced over 90 peer reviewed articles and presented over 200 reports at national and international meetings! I have also successfully trained five PhD students and have three PhD students in my lab, currently. I'm proud to be provide mentoring to several dental students, undergraduates and high school students.

What phrase sums up a career in dental and craniofacial genetics? Be intentional.

Azeez's *top tips*

- Trust the journey, focus on the clinical skills, and aspire to become the best dental scientist that you can be.
- Open yourself up for learning and mentoring.

Meet *Niki*

Niki leads the Moutsopoulos Lab, which studies oral mucosal immunity in health and disease.

Dr Niki Moutsopoulos

Associate Scientific Director, TT/ACI Faculty Development, Chief Oral Immunity & Infection Section, NIH National Institute of Dental and Craniofacial Research, National Institutes of Health, Maryland, USA

Fields of research
Immunology, Inflammation and Microbiology

Funder
Intramural programme of NIDCR/NIH

Glossary

Microbe — microorganisms which include viruses, bacteria, fungi and parasites

Oral mucosal — the mucous membrane inside the mouth

Periodontitis — gum disease that has progressed to the bone that surrounds the tooth

Food, air and many microbes enter our mouth constantly. Yet, the immune system of the mouth manages to protect us, so these outside elements do not cause harm, injury or disease. Oral mucosal immunity is the field that studies how the immune system in the mouth has evolved to protect us from the outside without causing constant injury, inflammation or disease.

We take a bedside-to-bench approach to studying oral mucosal immunity. We aim to understand oral diseases in people and help treat them. For this reason, we start our studies looking at oral health problems which we aim to solve so our work can help patients.

Periodontitis is a very prevalent disease – both in the US and worldwide. In its severe forms, it is estimated to affect close to 8% of the general population.

Research into periodontitis in our lab combines many types of work, ranging from seeing patients in the clinic to performing wet lab experiments, analysing data and applying computational approaches. We also spend a lot of time discussing data with co-workers and collaborators, preparing presentations and writing papers. There really is no 'typical day'!

While it's too early to assess the long-term impact of our work, we are thrilled that our lab has been able to partner with scientists and clinicians from many fields with the idea that diverse perspectives can help tackle complex questions in biology and medicine. I am also especially proud of the environment we have built in the lab over the past years with help from fantastic co-workers and staff. We have been able to foster a welcoming environment where enthusiastic junior scientists are encouraged to develop their talents and grow into independent investigators.

Niki's *top tips*

- Challenge yourself and try to ask important questions.
- Find mentors willing to support and push you forward.

Meet *Caroline*

Dr Caroline Shiboski

School of Dentistry, University of California San Francisco, USA

Fields of research
Orofacial Science, Oral Medicine and Epidemiology

Funder
NIH

Caroline studies how immune dysfunction can manifest in oral health problems.

Epidemiology helps us to understand the causes of diseases by trying to identify risk factors that may be associated with certain diseases. I chose to study epidemiology when I decided to specialise in oral medicine, which is like dermatology of the mouth, to better understand the many diseases that can happen in the mouth aside from tooth decay.

There are many diseases that affect the whole body, including the mouth. By looking inside the mouth, we can find clues to diagnose some of these diseases. It is like pieces of a puzzle with some of the pieces being found in the mouth.

The immune system can be weak. For example, when someone has HIV or if they have to take medication to lower the immune system after an organ transplant so the body will not reject it. If a person's immune system is weak, that person may develop more infections (from either bacteria, viruses or fungi), and some of these infections can happen in the mouth. On the other hand, the immune system can also be overactive

Glossary

Human immunodeficiency virus (HIV) — a condition where the body's immune system is unable to fight off infection or disease

Orofacial — relating to the mouth and face

Sjögren's disease — a condition where the body attacks glands that secrete fluid, such as the salivary glands

Tuberculosis (TB) — an infectious bacterial disease that most commonly affects the lungs but can affect any part of the body

when a person has what is called an autoimmune disease. There are many different autoimmune diseases with each one affecting a different part of the body that is being attacked by overreactive immune cells. This can happen in the mouth, when immune cells attack the lining of the mouth, causing ulcerations or sores. In the case of Sjögren's disease, it can also happen to salivary glands, when the immune system attacks the glands that produce saliva, preventing them from doing so and resulting in severe dryness in the mouth. When a person has little to no saliva, it can cause them to have very bad tooth decay or to develop yeast infections often. It also affects the way one can taste and swallow food.

I conducted studies in Zimbabwe looking at the progression of HIV among women. We found that women with more advanced HIV (i.e., who had fewer immune cell which can be measured by doing a blood test) had a much higher risk of having a yeast infection in their mouth (called oral candidiasis). We also did a similar study among adults with HIV and tuberculosis (TB) and found that those with TB were more likely to have oral candidiasis. These findings can be used to help screen for both HIV and TB (case-finding) in resource-poor settings where it is not feasible to do expensive blood tests on a large number of people to screen them.

My career highlights include having the opportunity to work with multidisciplinary teams such as HIV physicians and statisticians for my work in HIV, rheumatologists, ophthalmologists, oral pathologists, and statisticians for my work in Sjögren's disease. I also had the opportunity to lead a team to develop and validate classification criteria for Sjögren's syndrome (as it was called previously). Because Sjögren's disease does not yet have any effective treatment, clinical trials are needed to find good treatment for it, and participants need to be classified correctly as having or not having the disease to be able to join a clinical trial. Thus, the work on developing classification criteria for Sjögren's was very much needed.

What one word sums up a career in orofacial science? Multidisciplinary.

Caroline's *top tip*

Don't get into a lot of school debt to go to graduate school too early. Explore options for scholarship, training grants, etc.

Meet *Janice*

Janice is a surgeon scientist. She leads the Lee lab, focusing on craniofacial research.

Dr Janice Lee

Clinical Director, Craniofacial Anomalies and Regeneration Section, NIH National Institute of Dental and Craniofacial Research, Maryland, USA

Field of research
Craniofacial Anomalies and Regeneration

Funder
NIDCR/NIH

Glossary

Craniofacial — relating to the cranium (skull) and face

Genotype — all the genetic material within an organism

Loeys-Dietz syndrome — a genetic disorder that affects connective tissue (which helps structure other tissues and organs)

Phenotype — the physical characteristics of an organism

My work involves a range of conditions, some more prevalent and impactful on the patient than others. Common craniofacial conditions, such as underbite or overbite, have a global prevalence of 6% and 19.5%, respectively. These conditions can show up as you are growing and hit during puberty. Some of these are severe enough that they require facial surgery. Cleft lip and palate is the most common craniofacial difference seen at birth and occurs about 1.7 times in every 1,000 live births. Craniosynostosis (early fusion of the cranial bones which causes the skull shape to be abnormal) occurs in 1 in 2,500 live births. Hemifacial microsomia (in which one side of face, including eye, ear, lower jaw and facial nerve does not develop properly and causes facial asymmetry) happens in 1 in 3,500-5,600 live births.

Currently, my lab is studying skeletal malocclusions (severe underbite and overbites) to understand the genetics and shape changes, so we can predict who will develop the condition. It usually runs in families and can be a 'family trait'.

Using 3D computational analysis, specifically geometric morphometrics analysis, we are able to examine craniofacial development and compare the differences in healthy groups and individuals with specific diseases. This method is a form of phenotyping and is objective and quantitative; we can measure the differences. We use scans of the craniofacial skeleton or 3D photos of the face. With this analysis, we can see developmental differences that may be caused by genetic mutations. This helps us link the effects of a mutation to the impact on facial development, linking genotype to phenotype.

My patients are partners in my research. While caring for patients and their conditions, my surgeries can help one patient at a time. However, my research enables me to understand the condition in more detail, informs earlier diagnosis and predicts craniofacial development. This means we can treat or prevent the condition without invasive treatments like surgery. To do this, my research relies on a strong partnership with patients who contribute their time, data and experience to help me find answers.

My lab's success includes deciphering differences in craniofacial development between very small genetic changes (variants) in Loeys-Dietz syndrome. We have developed new 3D landmarks and a healthy craniofacial data set so that we can objectively compare them to disease groups. This will be available to the public and hopefully replace the older 2D methods and norms. We have also used computational methods to predict craniofacial growth.

The challenge of being a surgeon scientist is that there is not enough time to do everything, such as operate, care for patients, and do my lab research! Talking to patients about the advances we are making in my research that will help them and their families offers huge rewards.

What one word sums up a career in craniofacial research? Fulfilling.

Janice's *top tips*

- It's never too early to talk to clinician-scientists who are doing what you find interesting.
- Explore and find what excites you the most… then work doesn't feel like work.

Can artificial intelligence detect hidden heart attacks?

Analysing medical data to detect health problems can be incredibly difficult, but advances in artificial intelligence (AI) mean it is now possible for computers to spot subtle patterns in complex patient data. **Dr Salah Al-Zaiti** and **Dr Christian Martin-Gill**, from the **University of Pittsburgh** in the US, and **Dr Ervin Sejdić**, from the **University of Toronto** in Canada, are pioneering this technology to identify patients who have had hidden heart attacks, ensuring they receive medical treatment as quickly as possible.

Dr Salah Al-Zaiti

Professor of Nursing, Emergency Medicine, Cardiology, and Electrical and Computer Engineering, University of Pittsburgh, USA

Fields of research
Cardiology, Biomedical Informatics, Machine Learning

Dr Christian Martin-Gill

Associate Professor of Emergency Medicine, Department of Emergency Medicine, University of Pittsburgh, USA

Fields of research
Prehospital Care, Emergency Medicine

Professor Ervin Sejdić

Professor of Biomedical Engineering, The Edward S. Rogers Sr. Department of Electrical and Computer Engineering, University of Toronto, Canada

Research Chair in Artificial Intelligence for Health Outcomes, North York General Hospital, Toronto, Canada

Field of research
Biomedical Engineering

PROFILES

Talk like a ...

cardiologist

Acute coronary syndrome (ACS) — a group of conditions which stop or severely reduce blood flow to the heart muscle, commonly called a 'heart attack'

Algorithm — a set of rules that a computer follows to perform a function

Artificial intelligence (AI) — a type of machine learning in which a computer simulates human-like intelligence

Cardiology — the branch of medicine that studies the heart

Coronary artery — a blood vessel that supplies oxygen-rich blood to the heart muscle

Electrocardiogram (ECG) — a recording of the electrical signals from the heart

Ischemia — inadequate blood flow to the heart

Machine learning — the ability of a computer to learn and improve its performance by analysing data

Paramedic — a healthcare professional who treats patients before they arrive at hospital

ST elevation — when a specific section of a patient's ECG (known as the 'ST segment') is higher than normal, usually due to a blocked coronary artery (see figure on next page)

Stent — a tube placed in a blood vessel to keep it open

The human body is an incredibly complex system. Even the best doctors sometimes struggle to spot the subtle patterns in a patient's medical data that may indicate they have a health problem. Take a heart attack, for example. This life-threatening medical condition can be caused by a range of issues that reduce or prevent blood flow to the heart. Most heart attacks cause severe chest pain and shortness of breath, but these symptoms can also be due to other conditions, such as pneumonia or muscle spasms. While doctors can easily diagnose some types of heart attack, other heart attacks are harder to detect, and doctors and paramedics may misdiagnose a patient's chest pain as another medical condition.

After any type of heart attack, restoring the blood flow to the heart as quickly as

Research project
Developing an AI tool that can diagnose a heart attack from a patient's electrocardiogram (ECG)

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

possible is essential for preventing heart damage which, if left untreated, can be fatal. However, if doctors and paramedics are not aware that someone is experiencing, or has had, a heart attack, then precious time will be lost before the patient receives appropriate medical treatment.

Medically speaking, a heart attack is known as an acute coronary syndrome (ACS). "ACS represents a continuum of disease, ranging from partial to complete blockage of a coronary artery," explains Dr Salah Al-Zaiti, a researcher at the University of Pittsburgh who specialises in cardiology and machine learning. The coronary arteries provide the heart muscle with oxygen-rich blood, enabling it to contract and pump blood around the body. When a coronary artery is blocked, oxygen delivery to the heart is reduced – a condition known as ischemia. "Without oxygen, heart cells can die, causing irreversible damage," says Salah.

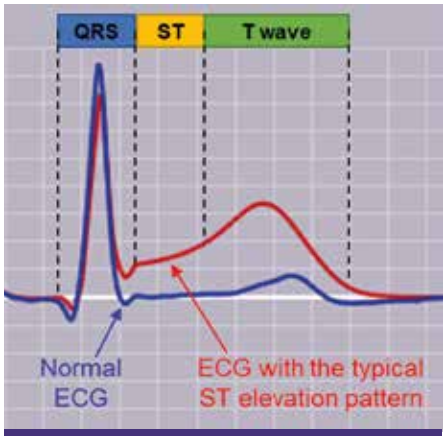
Electrocardiograms

If paramedics suspect a patient is having or has had a heart attack, they will take an electrocardiogram (ECG) to measure the patient's heart's electrical activity. "An ECG is recorded by placing electrodes on a patient's chest or extremities," explains Dr Christian Martin-Gill, who specialises in emergency medicine and prehospital care. Heart functions, such as contractions and relaxations, produce electrical signals which are detected by the electrodes and displayed on the ECG. "When the heart's function is altered, such as through ischemia, the electrical activity is also affected." This makes ECGs a powerful, non-invasive tool for detecting a wide range of heart conditions.

By using multiple electrodes on a patient's chest, doctors and paramedics can obtain what is known as a '12-lead ECG'. This provides different anatomical views of the heart and creates a 3D model of the heart's electrical activity, allowing for more precise medical assessment. "12-lead ECGs are specifically used by emergency personnel to check for ischemia in patients with chest pain," says Salah.

Electrical puzzles

You may recognise a typical ECG tracing of peaks and troughs from medical scenes on TV. As the heart should have a rhythmic function, ECGs should have repetitive segments that represent the heart's different activities. Variations in an ECG tracing can point towards disruptions in the heart's activity. "The most severe form of ACS, which involves complete coronary blockage, is frequently seen on an ECG tracing as an elevation of the ST segment," says Salah (see figure below). "However, some patients can have severe or complete blockages of a coronary artery, yet no ST elevation on their ECG. These patients represent a diagnostic challenge."



A comparison of an ECG with (red) and without (blue) ST elevation

Time is of the essence when dealing with a heart attack, as there is an urgent need to reopen the blocked coronary artery (by inserting a tube known as a stent) to allow blood to flow to the heart again. "If the ECG shows signs of ST elevation, paramedics immediately take the patient to a hospital with the facilities to place a stent in the blocked artery," Christian says. "However, even if the ECG does not have obvious ST elevation, other forms of heart attack can't be ruled out. This means the patient must still be sent to a hospital for further assessment, such as blood tests and scans." If the patient has had a heart attack, this time-consuming assessment delays the urgent process of reopening their blocked arteries. If the patient has not had a heart attack, the assessment has used often-limited healthcare resources.

Enter AI

12-lead ECGs give detailed outputs that are potentially highly useful for diagnosis. However, they are often so complex that it can be difficult to use them to draw conclusions about whether a patient has had a heart attack. "Prior studies have had limited success in identifying single distinct features of 12-lead ECG tracings that indicate severe coronary blockage," says Dr Ervin Sejdić, a biomedical engineer at the University of Toronto and North York General Hospital. "This is why we are turning to AI. AI can analyse complex combinations of ECG tracing features and, from these data, detect patterns other than the classic ST elevation."

Salah, Christian and Ervin have combined their expertise in medicine and machine learning to develop an AI tool that can detect subtle patterns present in the ECGs of heart attack patients that are invisible to the human eye. "To train our AI tool, we recruited over 4,000 patients who had chest pain but did not have the obvious ST elevation of a heart attack, and were, therefore, transported to hospital for further assessment," says Ervin. The ECGs of these patients were fed into the machine learning algorithm, which analysed them for patterns that existed in the patients who were confirmed to have had a heart attack but that were not present in patients who had not had a heart attack. "From these data, our AI tool identified unique subsets of ECG patterns that could identify coronary blockages," says Ervin. Once trained, the AI tool had to be tested and refined, so the team gave it ECG data from an additional 3,000 patients to analyse. "Our AI tool eventually outperformed experienced clinicians in its diagnosis of coronary blockage," says Salah.

Into the real world

Now that the team's AI tool can accurately detect coronary blockage in patients who do not have ST elevation on their ECG, the next step is to run a pilot study to test the system for real-time clinical use. "We are designing a web-based ECG dashboard that physicians can access remotely to check the AI-enhanced interpretation of ECGs obtained by paramedics," says Christian. The team will continue to evaluate the tool's accuracy and assess its usefulness for healthcare professionals, before deploying it more broadly. If all goes well, the tool has clear benefits for patients and healthcare staff alike. "Our AI tool can help identify patients with severe coronary blockage more quickly and accurately, which can improve their health outcomes," says Salah. "Additionally, it will also identify low-risk patients who can be safely discharged, freeing up precious hospital resources."

About *machine learning in medicine*

Healthcare is potentially on the verge of a revolutionary change. Advances in machine learning and AI mean that previously unidentifiable patterns in patient data can now be detected by computers. This is helping healthcare professionals to make more accurate diagnoses of medical conditions and to prescribe more appropriate treatments, and helping medical researchers to analyse the increasing amounts of biomedical data.

"Machine learning is making significant advancements in many areas of healthcare," says Salah. These include:

- Disease diagnosis based on patient data – such as Salah, Christian and Ervin's AI tool that analyses ECGs for signs indicating coronary blockage.
- Predicting the likelihood of disease development – for instance, looking at genetic or lifestyle traits that correspond with certain diseases.
- Medical imaging analysis – computers are now much better than humans at identifying variations in X-rays or MRI scans that might imply disease.
- Drug discovery – for instance, datasets about the effects of different drugs on the body can be fed into a machine learning algorithm to identify which drugs would be most appropriate for treating a specific disease.
- Healthcare operational efficiency – machine learning algorithms can suggest ways for healthcare services to operate more smoothly, such as by refining the triage process (the initial assessment of patients and prioritisation of their treatment).
- Remote patient monitoring – for example, if patients at home wear monitoring devices that record their health, the data can be analysed by machine learning algorithms to detect when the patient needs medical treatment.

While these areas have vast potential to change healthcare for the better, Salah emphasises that a lot remains to be done. "Machine learning in healthcare remains in its infancy," he says. "Most AI tools have been developed on retrospective data, so might still need robust evaluation using pre-diagnosis data before they can be approved for use. There are also many issues regarding access to medical data, patient privacy and the legal implications of analysing patient data." This highlights the important role of future practitioners who will help to usher in this new age of medicine.

Pathway from school to *machine learning in medicine*

- At school and post-16 years, study mathematics and computing to learn about statistics, data analysis and computer programming.
- Teach yourself to code using free online resources such as Code Academy (**www.codeacademy.com**).
- At university, a degree in machine learning, computer engineering or biomedical engineering will teach you the skills needed to build AI tools that you can use to address healthcare challenges.
- If you are interested in being a healthcare professional who uses machine learning, like Salah (a nurse scientist) and Christian (an emergency department physician), you will need to qualify as a medical practitioner by studying a degree such as nursing or medicine. Take courses in computer science and machine learning alongside your medical studies. The University of Pittsburgh School of Nursing runs regular events for prospective students to learn more about the courses offered and entry requirements: **www.calendar.pitt.edu/nursing**
- Gain medical experience by training as a first aider and volunteering with your local rescue squad.

Explore careers in *machine learning in medicine*

- As a machine learning scientist, computer engineer or biomedical engineer, you could find yourself designing, training and testing AI tools to address healthcare challenges.
- As a paramedic, nurse or doctor, you could use (and help develop) AI tools to diagnose and treat patients.
- Pharmaceutical companies need machine learning specialists to teach computers how to analyse data so they can develop better drugs, while bioengineering companies need machine learning specialists to teach computers how to analyse data so they can develop better biomedical devices.

Meet *Salah*

Growing up, my family had poor access to quality healthcare. I was born and raised in Jordan, and my parents were refugees of Palestinian descent. When I was 10, my father was hospitalised with breathing difficulties. He was initially admitted for pneumonia but was later diagnosed with acute myocardial infarction – a type of heart attack. My family wondered how doctors could miss a heart attack so easily, and this experience caused me to grow up with aspirations to reform healthcare.

I became an emergency nurse, taking care of patients when they are critically ill, and, during my graduate studies, I explored the use of technology for improving healthcare. I have always had a strong affinity to mathematics and engineering, which came in handy when I pursued advanced qualifications in applied machine learning.

As a researcher, I enjoy the discoveries and breakthroughs we make to solve today's healthcare problems. I also teach nursing students, and I enjoy inspiring the next generation of nurses who will take care of patients and make a positive impact on their lives.

I am very proud to have won a prestigious fellowship as a Fulbright US Scholar, for which I will spend a year in refugee camps in Jordan, using AI-powered ECG wearable devices to screen refugees for underlying heart diseases. This will be important work to improve access to healthcare in these marginalised populations.

Meet *Christian*

I trained as an emergency medical technician as I finished high school, and then became a paramedic while in college. I was attracted by the ability to care for people in emergency situations, outside of a hospital environment. Training as an emergency physician was a natural next step.

I spend part of my time working in the hospital emergency department, where I care for any patients who are brought in, regardless of their condition. This opportunity to begin a patient's care is a unique aspect of emergency medicine, and it allows me to work with people with a wide range of health conditions, from minor to life-threatening.

I also work alongside emergency medical personnel out-of-hospital, where I provide medical assistance to patients wherever they are, such as in their home, at the roadside or while they are being transferred to hospital.

As a flight physician, I travel with patients when they are being transferred between facilities by helicopter, to provide medical treatment during the journey.

The ability to help patients on a daily basis, in unique and challenging emergency situations, is very fulfilling and an ongoing achievement. My ambition is to continue to improve emergency medical services, whether through new technologies or better treatment protocols informed by research innovations.

Meet *Ervin*

My mother was diagnosed with cancer while I was in high school. Over the next several years, I witnessed how technology can have a profound impact on patients and their care. This motivated me to devote my scientific life to helping other people. After completing a PhD in electrical engineering, I joined a research lab at a children's hospital, where I immersed myself in applying engineering to various healthcare problems.

> ***Seeing these algorithms help clinicians and patients brings me an enormous amount of joy, as I know that my work matters.***

My work involves developing and deploying machine learning approaches in various healthcare settings. Seeing these algorithms help clinicians and patients brings me an enormous amount of joy, as I know that my work matters.

My proudest career achievement was being awarded the Presidential Early Career Award for Scientists and Engineers by President Obama. My ambitions for the future are very simple: helping as many patients as I can with my work. Being an electrical engineer by training, I would never have imagined that my work would have such a profound impact on human lives. It's really exhilarating.

A new paradigm in antibiotic research

Used for treating bacterial infections, antibiotics are an essential part of modern medicine. However, this crucial treatment option is in jeopardy. Antibiotic resistance – where bacteria become resistant to antibiotics – led to more than 1 million deaths worldwide in 2019. At the **University of Basel** in Switzerland, **Professor Christoph Dehio** leads the **National Centre of Competence in Research AntiResist**, which is applying new research methods to speed up the discovery and development of new antibiotics and complementary anti-infective strategies, thereby helping to reduce the problem of antibiotic resistance.

Professor Christoph Dehio

Biozentrum, The Center for Molecular Life Sciences, University of Basel, Switzerland

PROFILE

Fields of research
Molecular Microbiology, Infection Biology, Infectious Diseases, Bioengineering

Research project
Identifying new strategies to fight bacterial infections

Funder
Swiss National Science Foundation (SNSF)

Talk like an ...

infection biologist

Antimicrobials — a group of medicines that are used to treat infections, including antibiotics, antivirals, antifungals and antiparasitics

Bacterium (plural: bacteria) — a microscopic, single-celled organism

Consortium — a group of people or companies

In vitro — occurring in a controlled environment, such as a test tube or petri dish

In vivo — occurring within a living organism, usually animals, including humans

Microbe — a virus, or a microorganism, such as a bacterium, fungus or parasite

Pathogen — an organism that causes disease

Pneumonia — a life-threatening inflammation of the lungs, typically caused by an infection

Sepsis — when a surge in the body's immune response triggers inflammation throughout the body, causing a sometimes fatal cascade of organ damage

Antibiotics are medicines that kill or inhibit the growth of harmful bacteria. There are well over 100 antibiotics in total, but penicillin is by far the most prescribed and well known. Antibiotics are used to treat bacterial infections – such as bronchitis, tonsillitis and tuberculosis – but do not work to treat viral infections such as colds, flu or COVID-19.

"Antibiotics are essential for treating severe bacterial infection. Even a simple cut on a finger can develop a serious infection without appropriate attention, leading to the need for antibiotic treatment," explains Professor Christoph Dehio of the Biozentrum (Bio-centre) at the University of Basel. Antibiotics are indispensable for the treatment of patients with life-threatening infections such as sepsis or pneumonia, and for preventing infections while undergoing surgical procedures, cancer treatments and organ transplants.

Sadly, the effectiveness of antibiotics is under threat. More and more bacteria are evolving to become resistant to antibiotics and fight off the effects of antibiotic treatment. This is known as antibiotic resistance, and it is becoming a greater risk every day.

What is antibiotic resistance?

Antibiotic resistance is a type of antimicrobial resistance (AMR). Although these two terms sound similar, they are not quite the same. AMR is the general term for any microbe resisting any drug that was created to destroy it, including antibiotics, antivirals, antifungals and antiparasitics. Antibiotic resistance is a specific type of AMR in which bacteria resist antibiotics.

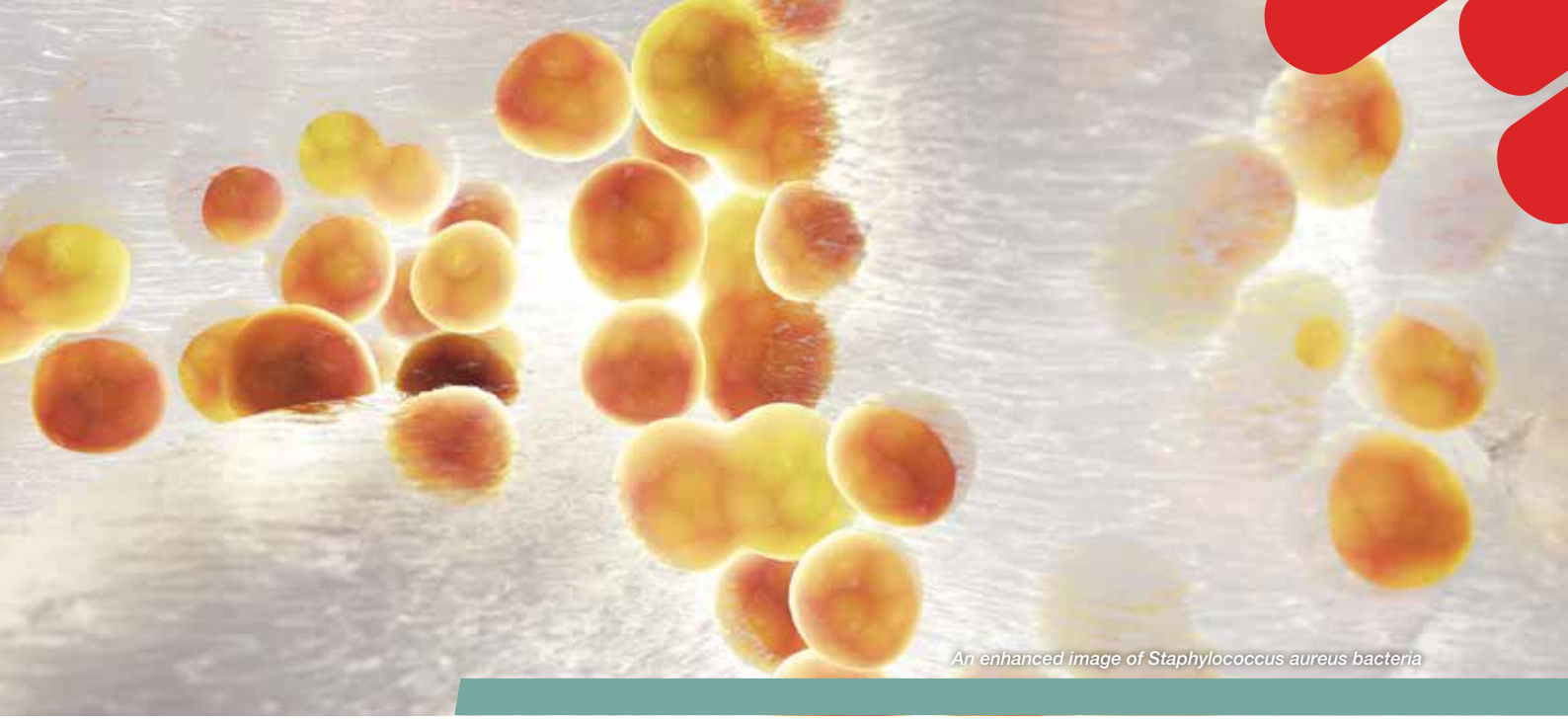
How much of a problem is AMR?

AMR has become one of the leading public health threats of the 21st century, with the World Health Organization (WHO) ranking AMR among the top 10 threats to global health. According to the Review on Antimicrobial Resistance* (2016), if more is not done to appropriately address the problem of antibiotic resistance, it could cause 10 million deaths a year by 2050 – more than cancer and diabetes combined.

"Many bacteria can resist one or more antibiotics, meaning that infections caused by those bacteria are hard for doctors to treat," explains Christoph. While bacteria learn to become resistant to antibiotics naturally over time, poor patient hygiene, lack of access to clean water, over-prescription of antibiotics, and patients taking antibiotics inappropriately can all increase the speed at which antibiotic resistance occurs.

What can be done to tackle AMR?

One important measure to slow down AMR is to use existing antibiotics in the most effective way. This means avoiding unnecessary use of antibiotics and ensuring that whenever an antibiotic is used, it is used with care to minimise the risk of AMR development and spread. This approach,



An enhanced image of Staphylococcus aureus bacteria

known as antibiotic stewardship, can prolong the period of effective use of an antibiotic for treating patients, but does not resolve the problem of the evolutionary 'arms race' ultimately leading to AMR. We urgently need to develop new effective antibiotics that bacteria do not yet know how to resist. However, this solution is not easy.

The first ever antibiotic – penicillin – was discovered by Scottish microbiologist Alexander Fleming in 1928. Over the next 60 years, new antibiotics were discovered regularly. However, the discovery of an antibiotic is not the same as it being available for use. The last new class of antibiotics made available to treat patients was developed over three decades ago, and no more have been developed since. "The lack of new antibiotics is a result of many complex scientific, clinical and economic challenges," explains Christoph. "With our new approach, we aim to reinvigorate antibiotic discovery and development."

What is Christoph's approach?

Christoph is the director of a research consortium called the National Centre of Competence in Research (NCCR) AntiResist, which aims to tackle the rapid and worldwide increase in AMR by developing new, innovative antibiotics. The project is based at the University of Basel, where Christoph works, and includes 30 research groups in Switzerland and one in Israel.

The research project is interdisciplinary, involving doctors, biologists and bioengineers, as well as experts from chemistry, computation and pharmacology. The NCCR AntiResist team also works with pharmaceutical companies that will help produce the new antibiotics that the project discovers.

Which bacteria is the project working on?

NCCR AntiResist is focusing on four difficult-to-treat pathogens: *Escherichia coli*, *Pseudomonas aeruginosa*, *Staphylococcus aureus* and *Brucella melitensis.*

Antibiotic-resistant strains of *Escherichia coli* (*E. coli)* have been listed by the WHO as the highest priority for research and development of new antibiotics. "Most *E. coli* strains are harmless, but some cause serious infections, including food poisoning, septic shock, meningitis, and urinary tract infections (UTIs)," explains Christoph.

The second pathogen, *Pseudomonas aeruginosa*, is listed by the WHO as a critical priority. It is frequently found in serious infections such as pneumonia, sepsis, burns, and wound infections.

NCCR AntiResist's third pathogen of focus, *Staphylococcus aureus*, is causing an increasing number of deaths worldwide due to pneumonia, and skin and soft-tissue infections.

The fourth pathogen, *Brucella melitensis*, causes the chronic debilitating disease brucellosis. People most commonly get this disease by eating unpasteurised dairy products that come from infected sheep, goats, cows or camels.

The AntiResist team is targeting these four bacterial pathogens as their resistance to antibiotics makes them the most threatening to global health. "Our ultimate goal is to use our ground-breaking approach to find new types of antibiotics and other innovative anti-infective therapies that are able to treat infections caused by these bacteria," Christoph explains.

How does the project work?

The AntiResist project has multiple phases which all require close collaboration between medical doctors, biologists and bioengineers.

"Recent attempts to discover new type of antibiotics in the laboratory – *in vitro* – struggle when clinically tested on people," says Christoph. To avoid this, the NCCR project performs its studies both *in vivo* and *in vitro*.

Firstly, medical doctors within the AntiResist team gather samples of bacteria from infected patients. This means the process starts by working directly with human tissue. "Studying microorganisms inside human tissue – *in vivo* – enables us to learn more about bacterial behaviour and its interactions inside the infected patient," explains Christoph.

After sampling tissue from the patient, samples are transferred from hospitals to laboratories, where they are studied by biologists. "Biologists analyse the samples using highly sensitive, state-of-the-art analytical methods," explains Christoph. "The results are then used to develop micro-tissue models that simulate the conditions in the human tissue as accurately as possible. This is the laboratory – *in vitro* – phase."

These micro-tissue models are developed by growing a tissue inside a culture dish in conditions that mimic the environment of the human body. After the micro-tissue is fully developed, the biologists introduce bacterial cells to the dish and observe what happens, how the bacteria move and replicate, how they infect the tissue and how the tissue might defend itself.

Once the biologists are satisfied with how these models are working, they collaborate with bioengineers to take the first steps towards discovering new antibiotic treatments.

What has the team found so far, and what is next?

The AntiResist team is coming to the end of the first phase of its research, during which it has gathered human tissue samples, analysed them in the laboratories, and begun to create the *in vitro* models.

During the second phase of the project, the team will identify the specific ways that each tissue was infected by bacteria, and the mechanisms involved. "From there, we will be able to pinpoint vulnerable factors of the bacteria to target," says Christoph. This means that the NCCR team and their collaborators in the private sector will use the developed models and their knowledge on vulnerable bacterial factors to identify novel antibiotic compounds and principles.

In the third, final, phase, the goal of NCCR AntiResist is to develop these antibiotic compounds and principles further to eventually move the research into clinical trials, which is one step away from introduction into clinical practice. Keep your eyes peeled to see what treatment options we might have in the future!

* **amr.review.org**

About *infection biology and antibiotic research*

Spread across 31 research groups, the NCCR AntiResist team consists of biologists, chemists, clinicians, bioengineers, computer scientists and physicists. The range of expertise within the team highlights the complexity of the research challenge and the multidisciplinary approach the team is taking to tackle it. It also shows that there is not one set career pathway you must follow to contribute to antibiotic research; many research interests could enable you to do so. From clinical studies looking at how pathogens 'behave' in an infected patient to modelling how new antimicrobials could work, from developing technologies that enable genetic analysis of pathogens to developing sophisticated databases to store and interpret the huge amount of data such research generates, the career opportunities offered by infection biology and antibiotic research are wide and varied.

The ambitions of NCCR AntiResist highlight the innovative research required for progress in this field, and Christoph and the team believe that the next generation of researchers have an important part to play in this. "We hope that young scientists who want to make a difference in the AMR field will learn a new research approach to tackle resistances," explains Christoph. He emphasises that the future of research in this vital field is multi-faceted and multi-disciplinary: "Being able to gain insights from other fields of expertise can be inspiring to your own work and paves the way for great advances in knowledge."

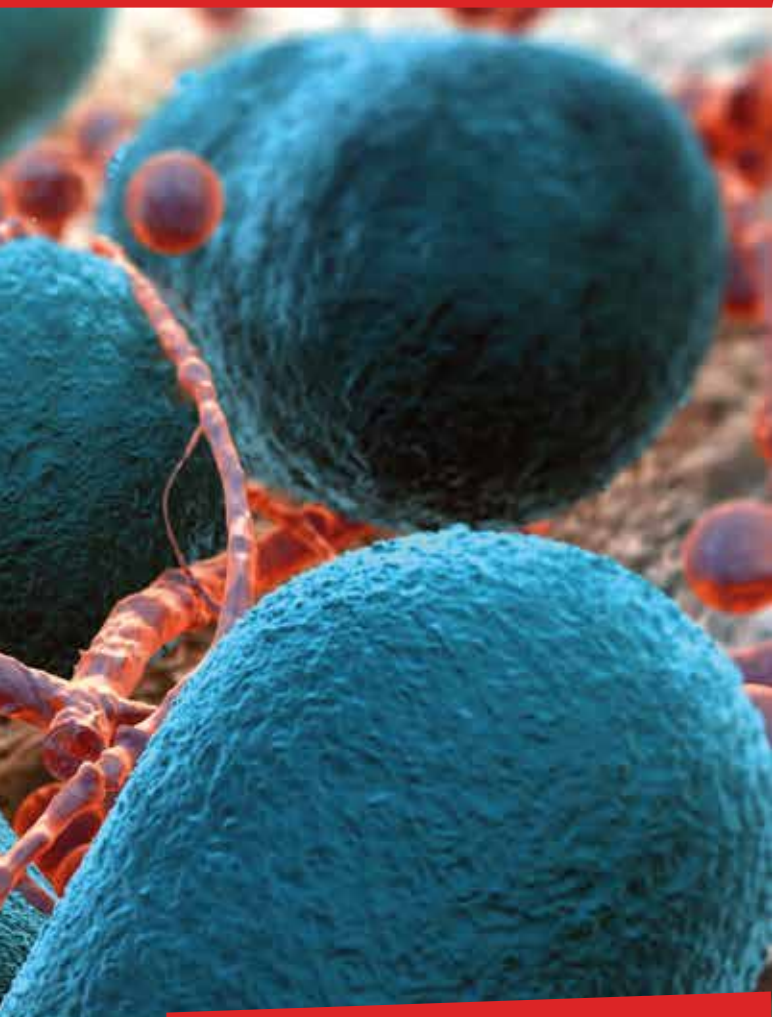
To ensure it is preparing a new generation of scientists to keep moving research forward, the NCCR AntiResist team is committed to giving its students opportunities to gain research experience outside the classical disciplinary route. "As part of our work, we ensure that our Master's and PhD students are exposed to different disciplines, so that they are prepared and qualified to carry our approach into future scientific discoveries," says Christoph. "Our consortium offers PhD fellowships which give students the opportunity to choose between biology, clinical and engineering laboratories in their first year. These students work across at least two disciplines, so that they gain expertise in a truly interdisciplinary context."

Antimicrobial resistance will be an ongoing challenge, and Christoph and the NCCR AntiResist team are ensuring that scientists and researchers – both now and in the future – are able to meet it head on.

Pathway from school to *infection biology and antibiotic research*

- The NCCR AntiResist researchers work across clinical, biological and engineering fields, representing a wide variety of academic backgrounds. As well as biology, subjects such as chemistry, computing and engineering-related subjects are relevant. If you look at the 'People' pages on the AntiResist website (**www.nccr-antiresist.ch/en**), you can see the detailed CVs of the team's principal investigators and the variety of qualifications and expertise within the consortium.
- "At the Biozentrum (Bio-centre) in Basel, there are regular public lectures called 'Einblicke' open to anyone who wants to attend," says Christoph. The calendar of events starts afresh every September: **www.biozentrum.unibas.ch/events/biozentrum-einblicke**
- As the NCCR AntiResist team highlights, research in this area crosses countries, as well as disciplines. Christoph says, "Be proactive and start searching online to find out what work is going on in your country. Search terms such as 'microbiology', 'microbes', 'infection biology', 'drug development', 'antibiotic research' and 'antibiotic resistance'. There is a wealth of resources to explore."
- To find more challenging content and scientific papers, Christoph advises searching on Google Scholar (**scholar.google.com**), using terms such 'AMR' or 'antibiotic research'.
- "The ReACT toolbox (**www.reactgroup.org/toolbox**) is a very useful site for learning about antibiotic resistance, the latest scientific research and ways to raise awareness," says Christoph.

An enhanced image of E. coli bacteria



Explore careers in *infection biology and antibiotic research*

- The PhD students who work with Christoph come from a wide range of backgrounds, from medicine to data science, engineering to biochemistry and microbiology, which highlights the scope of disciplines and career paths linked to infection research. Visit the NCCR AntiResist website, where you can read about the different routes the PhD fellows took before joining NCCR AntiResist: **www.nccr-antiresist.ch/en**

- In the UK, Prospects provides information on a range of careers that could see you playing a role in infection research. For example, in data science (**www.prospects.ac.uk/job-profiles/data-scientist**), biochemistry (**www.prospects.ac.uk/job-profiles/clinical-scientist-biochemistry**), microbiology (**www.prospects.ac.uk/job-profiles/microbiologist**) and medicine (**www.prospects.ac.uk/careers-advice/what-can-i-do-with-my-degree/medicine**).

- You can read about how other researchers – from varying fields – are studying antibiotic resistance and the career paths they have taken in other Futurum articles. For example, from the perspective of a chemical microbiologist (**futurumcareers.com/how-can-we-discover-new-antibiotics**), a chemical engineer (**futurumcareers.com/the-need-for-antimicrobial-peptides-in-a-world-of-antibiotic-resistance**) and medical anthropologists (**futurumcareers.com/how-poverty-contributes-to-antimicrobial-resistance**).

- The American Society for Microbiology hosts a podcast, Editors in Conversation, which highlights different pathways to follow careers in antimicrobial research: **asm.org/Podcasts/Editors-in-Conversation/Episodes/Research-Careers-in-Antimicrobial-Resistance-EIC-5**

Meet *Christoph*

I grew up on a farm and have always been fascinated by nature in all its manifestations and interested in exploring its mysteries. In my final year at school, I visited Dietrich von Holst, a distant relative who, at the time, was Professor of Animal Physiology at the University of Bayreuth in Germany. His physiological and behavioural studies of stress in tupaias (tree shrews) fascinated and inspired me to take the academic route and become a scientist and researcher.

Serendipity has played a significant role in shaping my career, but I am also grateful for the guidance and support of mentors who have provided me with the necessary freedom to grow into an independent scientist. Their mentorship has been instrumental in helping me navigate the academic path and advance through the ranks.

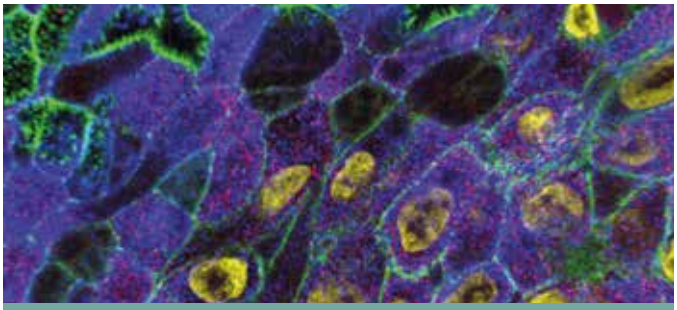
There have been eureka moments at every stage of my academic career. For example, as a young postdoc at Institut Pasteur, I discovered that infection of human cells by the bacterial pathogen *Shigella* triggers the activity of a protein involved in cancer (a so-called proto-oncogene). As is the case in every scientist's career, these moments are few and far between, but when they do happen, they drive the urge for research progress.

My success as a scientist and in overcoming obstacles stems from my curiosity, perseverance, excitement for research, independence and willingness to collaborate.

I am particularly proud of several things in my career. Firstly, I am proud that I – together with my research team – pioneered and advanced molecular studies on the emerging pathogen *Bartonella*, which led to a detailed understanding of the molecular infection process and offered interesting targets for treatment and prevention. Secondly, that a sizeable number of scientists trained in my lab are now leaders in academic research and industry. Thirdly, with the support of my colleagues and the Swiss National Science Foundation, we launched the NCCR AntiResist project, which could significantly change the way we discover and develop anti-infectives in the future.

Christoph's *top tip*

Do what you like best, and do it with full dedication.



An image of Pseudomonas aeruginosa captured in one of AntiResist's research laboratories

How can intelligent systems revolutionise healthcare?

Access to quality healthcare is a basic human right. Without doctors, nurses and hospitals, our societies would cease to function. However, all over the world, the pressure on health care systems is mounting due to ageing populations and many other factors. **Dr Narges Armanfard** from **McGill University** and **Mila Quebec AI Institute** in Montreal, Canada, has set up **iSMART Lab** to develop intelligent computer systems that can support medical professionals.

Professor Narges Armanfard

iSMART Lab, McGill University and Mila Quebec AI Institute in Montreal, Canada

PROFILE

Field of research
Intelligent Systems

Research project
Developing cutting-edge technologies for health monitoring

Funders
McGill University, Fonds de Recherche du Québec, AGE-WELL, Vanier Canada Graduate Scholarships, Natural Sciences and Engineering Research Council of Canada

Talk like an ...

intelligent systems engineer

Algorithm — a sequence of rigorous instructions or rules that are used to solve complicated problems

Artificial intelligence (AI) — the replication or simulation of human intelligence using machines, especially computers

Bias mitigation — preventing or reducing unconscious bias (that can impede human reasoning)

Intelligent systems — advanced machines or computers that are able to perceive and respond to the world around them

Machine learning (ML) — computer systems able to learn and adapt without following specific instructions

Responsible AI research — AI research that ensures new advancements do not put anyone at risk of exploitation or harm

Telemedicine — using electronic communication devices to provide health care when the doctor is not in the same location as the patient

Wearable devices — small devices, such as a wristband or implant, that an individual wears to monitor their physical condition

Thanks to medical advancements and better lifestyle choices, humans are now living much longer than we used to. In 1950, the United Nations estimated that there were 23,000 people around the world who were over the age of 100. By 2021, that estimate had rocketed to 573,000.

As we get older, we start to encounter more health complications. For example, the World Health Organization estimates that 47.5 million people live with dementia worldwide, and this figure is expected to increase. Although our ability to treat age-related diseases has improved dramatically over the last few decades, health care systems are beginning to feel the strain of caring for an ageing population.

Medical waiting lists are getting longer, hospitals are running out of beds, and doctors and nurses are burning out. These problems are caused by several factors, including consequences of the COVID-19 pandemic, increasing rates of obesity, and a lack of staff and funding. To ease the pressure on our struggling healthcare systems, scientists and medical professionals are looking to innovative new technologies such as machine learning (ML) and artificial intelligence (AI).

Dr Narges Armanfard, from the Department of Electrical and Computer Engineering at McGill University and Mila Quebec AI Institute in Montreal, has established iSMART Lab to develop new healthcare technologies. "iSMART Lab is at the forefront of developing cutting-edge technologies for health monitoring through the use of intelligent systems," says Narges. "My iSMART Lab is attempting to revolutionise how healthcare professionals and individuals monitor and manage their health."

Patient well-being

Intelligent systems are innovative computer systems that can perceive and respond to the world around them. One key aspect of such systems is AI algorithms, which can analyse vast amounts of data in a short space of time.

By analysing data from various sources, such as wearable devices, health records and lifestyle

habits, these systems can provide personalised insights into an individual's health. This can enable people to make informed decisions and take proactive measures to maintain their well-being. "Whether it's tracking physical activity, monitoring vital signs, analysing sleep patterns or brain activities, intelligent systems can provide real-time feedback and recommendations to encourage healthier habits, behaviours, and early and accurate diagnosis and prognosis that may not be evident to the human eyes," explains Narges. Intelligent systems can act as virtual assistants to individuals and healthcare practitioners. For example, these systems can guide older adults or people with dementia by offering reminders for taking medicine, suggest healthy recipes, or curate exercise routines that can help people stay fit and reduce the risk of certain diseases.

Intelligent systems can offer personal guidance based on their analysis of a person's health data. "This can enable individuals to actively participate in management of their own health, empowering them to lead healthier, more balanced lives," says Narges. Additionally, intelligent systems can help to detect early signs of abnormalities in the brain, tailoring treatment plans for individuals with brain disorders. "Early detection of abnormal activities and related abnormal areas in the brain can assist neurologists to help patients manage their conditions and minimise the brain disorder's severity to improve a patient's quality of life," explains Narges.

Aiding healthcare providers

Intelligent systems can provide invaluable assistance to healthcare providers and have the potential to transform patients' experiences of the healthcare system. "By leveraging AI algorithms, these systems can detect patterns and trends in patient data that may not be easily identifiable to human observers," explains Narges.

Healthcare professionals will be able to detect diseases at an earlier stage, enabling them to make more accurate diagnoses, predict potential complications, and personalise treatment plans to best suit each patient. "Additionally, intelligent systems can streamline administrative tasks such as documentation, scheduling and billing, allowing healthcare providers to allocate more time and attention to direct patient care," says Narges.

Intelligent systems can also facilitate better communication and collaboration between healthcare teams. "These systems can securely store and share patient information, ensuring that healthcare professionals have access to comprehensive and up-to-date data, regardless of geographical location," says Narges. This seamless flow of information enables different teams to coordinate, makes the delivery of care more efficient and reduces the chances of errors being made due to miscommunication or confusion.

Another advantage of intelligent systems is that they can support telemedicine and remote monitoring. This allows doctors to monitor their patients, consult with them and make decisions about their treatments from afar. This could be particularly important in areas that lack access to sufficient healthcare facilities, or during emergencies, such as natural disasters and pandemics.

iSMART Innovations

"The projects we work on aim to transform the monitoring and management of health conditions," says Narges. By combining AI algorithms with new monitoring technologies, iSMART's projects enable real-time, non-invasive monitoring of patients from within the comfort of their own homes. This approach allows doctors to collect data continuously and over longer periods of time, allowing them to provide personalised treatments that specifically address the needs of each patient. Moreover, iSMART aims to provide software platforms whose output will be a great asset to neurologists to make prompt diagnosis and treatments for patients with brain disorders.

What makes iSMART Lab projects unique is their ability to analyse a range of data sources, including video recordings, audio signals, physiological signals, movement patterns and environmental data. Integrating AI and smart-home technologies into these intelligent systems can empower individuals to actively manage their own conditions and improve their quality of life. As another example, integrating AI into the brain analysing intelligent systems facilitates thpredictions of a disease's progression, allowing neurologists to make informed decisions about treatment strategies and care planning.

The AI revolution

"AI has the potential to revolutionise our lives in numerous positive ways," says Narges. "Responsible AI research and development can lead to advancements in various fields, including transportation, education and sustainability."

AI could optimise our transport systems by reducing congestion, planning out delivery routes for goods vehicles, and controlling self-driving cars. In education, AI can personalise learning experiences to suit a person's preferred learning style, encouraging engagement. In the world's fight against climate change, AI algorithms can help by monitoring carbon emissions, predicting changes to weather patterns and optimising our energy use.

"The iSMART Lab plays a crucial role in driving responsible AI research and development," says Narges. "The lab is prioritising ethical considerations, transparency and accountability in AI systems by focusing on fairness, bias mitigation and privacy protection." The iSMART Lab will help ensure that AI technologies are developed with the well-being and rights of individuals as priorities.

"The lab also promotes interdisciplinary collaboration, bringing together experts from various fields to address societal challenges and explore the potential of AI for positive impact," explains Narges. The iSMART Lab is developing guidelines and frameworks for responsible AI ensuring that AI is used ethically and in a responsible manner to benefit humankind, rather than control it.

Zero-effort health smart home

Smart home technologies are devices that can monitor a patient's health from within their own home. "The aim of health smart home (HSH) is reducing pressure on the health system while providing timely e-health services to its occupants (e.g., older adults) wishing to live in their own homes and maintain their independence," says Narges. "Zero-effort-HSH (Z-HSH) aims to realise HSH goals so that neither active interaction or compliance from the user is required, and the user does not need to wear any sensor or device. More specifically, in Z-HSH, technology is embedded into the common household items and does not interfere with the daily activities of the smart home occupants," explains Narges. Hadi Hojjati, a PhD student working on this topic under supervision of Professor Narges Armanfard, is developing advanced AI algorithms that can analyse massive amounts of health data to ensure healthcare professionals can make the most of these smart home technologies.

What are the healthcare benefits of smart home technologies?

Smart home technologies are more convenient than traditional methods and reduce the need for frequent hospital visits. They are also able to collect data continuously, throughout the day and night, which helps doctors make informed decisions about a patient's health.

"Health smart home devices can capture physiological signals, such as heart rate and blood pressure, as well as track users' sleep patterns, steps taken and calories burned," explains Hadi. "For instance, wearable devices like fitness trackers or smartwatches can continuously monitor the heart rate and provide insights into users' physical activities, such as walking or running."

One of the key advantages is early detection of health issues. "For example, sensors can monitor movements and identify unusual patterns that may indicate a fall or decline in mobility, allowing caregivers to intervene quickly," says Hadi.

What makes analysing data from smart home sensors so challenging?

Smart home sensors are continually collecting large volumes of complex and variable data. Additionally, each patient's data will exhibit their own unique patterns and trends, which make analysing and comparing datasets more difficult.

"Traditional analytical approaches may struggle to handle this variability and extract meaningful insights," says Hadi. "To tackle these challenges, deep-learning methods are being developed which can automatically learn and identify patterns from vast amounts of data."

These deep-learning algorithms aim to improve the accuracy, efficiency and personalisation of healthcare based on smart home sensor data. They enable doctors to better understand health conditions and individual needs, which can lead to more effective and targeted treatments.

What privacy issues need to be considered?

"When developing health smart home algorithms, it is crucial to address privacy concerns to safeguard personal information," says Hadi. Smart home devices gather sensitive health-related data which must be stored securely. Smart home devices must have robust security measures to prevent unauthorised access and protect patients' privacy.

"Informed consent emerges as another critical aspect," says Hadi. Users should be aware of the data that are being collected, how they are used, and who has access. Smart home devices should prioritise transparency and give patients control over their own data, allowing them to opt-out, delete data, or increase their privacy.

What challenges does this research pose?

One challenge that Hadi and iSMART Lab face is the

lack of well-developed algorithms in this area. The team must invest time and resources into developing new algorithms that are specifically designed for analysing smart home data.

Another challenge is the lack of comprehensive datasets that the team can use to train and test their new algorithms. "Unlike other domains where large datasets are readily available, smart home datasets are often limited and fragmented, mainly due to privacy regulations," explains Hadi. "The iSMART Lab team must overcome this hurdle by curating or creating their own datasets, which requires significant effort and expertise."

How successful has this research been?

Hadi and the iSMART team have demonstrated that smart home sensors can effectively record information about physiological signals such as a patient's heart rate or blood pressure. As they continue to refine their algorithms, they will be able to analyse these signals in more detail.

For example, Hadi is hoping to use multimodal learning, which involves combining data from multiple kinds of sensors, to create a more complete view of a patient's health. "Providing more accurate and insightful health monitoring solutions will open up a lot of possibilities," he says. "We can keep track of our health at a much lower cost, making healthcare more accessible and affordable for everyone." Smart home technologies could replace the need for expensive equipment and frequent visits to hospitals.

Pathway from school to *intelligent systems engineering*

- It is essential to have a strong foundation in technical skills and knowledge. Studying physics, maths and computing at school and post-16 years is a good place to start.
- Staying up to date with the latest advancements in the field of AI and ML is important.
- Work on your problem-solving skills. Being able to break down complex problems and find innovative solutions will be helpful.
- Persevere and be resilient. The ability to embrace failures as learning opportunities will help you grow as a scientist.
- Practise your communication skills. Being able to convey complex concepts in a clear manner can help you share your work and collaborate with others. Strong interpersonal skills will also help you make connections and work effectively with a range of people.

AI for brain disorders

The projects at iSMART Lab go beyond smart home technologies. Thi Kieu Khanh Ho is a PhD student, under the supervision of Professor Narges Armanfard, investigating how advanced AI algorithms can help medical professionals detect and diagnose epilepsy.

How is epilepsy detected?

There are currently two main methods for detecting epilepsy: electroencephalograms (EEGs) and magnetic resonance imaging (MRI). An EEG involves placing electrodes on a patient's scalp or surgically embedding electrodes into a patient's brain. These electrodes are used to record electrical activity within the brain and help to identify abnormal brain activity, such as seizures, or seizure on-set zones, the parts of the brain where the seizures originate. "On the other hand, MRI is an imaging technique that provides detailed structural images of the brain and helps neurologists to identify the underlying cause of epilepsy," explains Khanh. Currently, medical professionals must visually study these brain signals and images besides patients clinical information to identify any brain abnormalities which might be causing the seizures. This can be a very time-consuming and costly process. "Our experiments, in collaboration with the Montreal Neurological Institute, confirm that there could be important information hidden in the patient's brain related data that can not be discovered by human eyes," says Narges.

How can AI algorithms help?

To tackle these challenges, Khanh is developing new AI algorithms that will be able to use EEGs and MRIs to automatically detect seizure on-set zones. These will be self-supervised learning (SSL) algorithms, meaning that they can make sense of and categorise raw, unlabelled data, saving medical professionals time and money.

Khanh is developing separate algorithms that analyse data from scalp EEGs, intercranial (within the cranium – or skull) EEGs, and MRI images. However, she is hoping to integrate these three methods into one SSL-based multimodal technique that will be better able to identify seizure on-set zones and other abnormal regions.

What impact could this have on epilepsy treatment?

One common form of epilepsy treatment is resective surgery, where the part of a patient's brain which is causing seizures is removed. "The ultimate product of our epilepsy project is a software platform which will be a great asset to neurologists when deciding which brain regions must be resected during epilepsy surgery," says Khanh.

Could these AI algorithms be applied to other brain disorders?

"Our proposed AI framework aims to detect abnormal brain activities and related brain regions in epilepsy patients using different modalities, namely EEG signals and MRI images," says Khanh. "The current practice of identification of other brain disorders is also mainly based on these modalities." As a result, Khanh believes her algorithms could be used to detect abnormal brain activity and the related brain regions of other brain disorders.

What are the challenges of this research?

This research requires interdisciplinary collaboration between computer scientists and neurologists. Khanh's job as a computer scientist is not only to develop AI models that can accurately detect abnormal brain activity, but also to ensure the findings of these models can be interpreted properly.

"Understanding the reasons behind a model's decision is important to validate the findings, gain insights and ensure the reliability of the model," explains Khanh. "At the same time, we need to incorporate the knowledge of neurologists, who are experts in recognising abnormalities and able to evaluate the performance of our models."

Once Khanh has succeeded in creating AI models that are accurate and reliable, moving these models from research into clinical practice will be a significant challenge. The models must be rigorously tested and validated, and integrated into existing clinical practices. "As the EEGs and MRI datasets are continuously generated, our models must be adaptable and capable of handling new data to yield up-to-date and accurate predictions," she says.

What successes has this project achieved so far?

"We have verified our self-supervised method on detecting and localising seizures using the largest publicly available scalp EEG seizure dataset," says Khanh. The team was able to show that its self-supervised learning method overcame many of the problems faced in previous seizure detection research. This method also significantly reduced the time and resources needed to achieve successful detection.

What are the next steps for this project?

Khanh's main focus is finalising the AI framework which will integrate data from both EEG signals and MRI images. She says, "We will also consult the opinion of neurologists on the performance of our methods, then we will apply our methods to the identification of other brain disorders."

© metamorworks/Shutterstock.com

Explore careers in *intelligent systems engineering*

- There are many places online that you can visit to learn more about intelligent systems and AI including The Society for Intelligent Systems (**intellisys-society.org**), the Association for the Advancement of Artificial Intelligence (**aaai.org**), and the AI Association (**www.theaiassociation.org**).
- Many universities run summer schools dedicated to machine learning and AI. Contact your local university to see whether they have any opportunities, or follow this link to see a list of summer schools from all over the world: **github.com/sshkhr/awesome-mlss#2023-summer-schools**

Meet *Narges*

As the founder of the iSMART Lab, I firmly believe in the power of teamwork and effective leadership. I recognise that innovation thrives in collaborative environments where diverse talents converge towards a common goal. My philosophy centres on fostering an inclusive and dynamic atmosphere where each member's strengths are harnessed and contributions valued. Through open communication, shared vision and a commitment to continuous learning, I aim to cultivate a strong sense of camaraderie within iSMART Lab. By leading with empathy, integrity and a dedication to empowering my team, I strive to inspire and guide individuals to reach their full potential and collectively drive impactful research and advancements.

I have always had a curiosity and passion for understanding how things work and solving complex problems. This natural inclination towards science and technology sparked my interest in pursuing a field where I could delve into the intricacies of electrical and computer systems.

I am inspired by the trailblazing women who have made significant contributions to the field of engineering. Their perseverance, resilience and determination in breaking gender barriers motivate me to follow in their footsteps and contribute to increasing diversity and representation in the field. I am inspired by their stories of overcoming challenges and defying societal norms, proving that women can excel and thrive in engineering and STEM disciplines.

The mentors and professors during my academic journey have played a crucial role in shaping my career choice. Their mentorship has not only provided me with technical knowledge but also instilled in me the desire to make a positive impact through my work.

Establishing iSMART Lab has been the culmination of my passion for AI, research and societal impact. Throughout my academic journey, I witnessed the transformative potential of AI and its applications in various domains. I was driven by a desire to contribute to the advancement of AI technology and harness its power for the greater good.

I noticed the need for a dedicated research space that focuses on responsible AI development and interdisciplinary collaboration. I envisioned a lab where innovative ideas could flourish, ethical considerations could be prioritised, and diverse perspectives could be embraced.

I wanted to create an inclusive environment that promotes diversity and encourages the participation of underrepresented groups in AI research and development. iSMART Lab became a space where aspiring researchers, especially young women, could find support, mentorship, and opportunities to thrive in the field of AI.

It is immensely satisfying to witness the growth and success of lab members, seeing their ideas come to fruition and contribute to advancing knowledge and technology. Leading a lab provides a platform to mentor and guide aspiring researchers, shaping their careers and empowering them to make their own contributions to the field.

Leading a lab also comes with challenges. Managing resources, securing funding, and maintaining a productive and cohesive research environment require careful planning and coordination. Balancing administrative responsibilities with research and teaching commitments can be demanding and time-consuming. Moreover, fostering collaboration and maintaining effective communication within a diverse team can present its own set of challenges.

To switch off from work, I prioritise self-care and maintain a healthy work-life balance. Engaging in activities outside of work helps me recharge and maintain a fresh perspective. I make sure to set boundaries and allocate dedicated time for relaxation, hobbies and spending quality time with loved ones.

> ***I believe we can develop AI technologies that are more inclusive, unbiased and aligned with societal needs.***

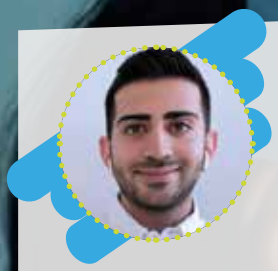
To overcome obstacles, I seek support from my professional network and engage in open conversations with colleagues and mentors. Sharing experiences, challenges and strategies with others in the field helps me gain new insights, find innovative solutions and overcome obstacles more effectively.

I am proud of my contributions to cutting-edge research projects that have pushed the boundaries of AI technology. From developing novel algorithms to tackling real-world problems, these research endeavours have allowed me to make a tangible impact in the field and advance knowledge in AI.

I am also proud of my role as a mentor and educator. Guiding and inspiring the next generation of AI researchers is immensely fulfilling. Seeing my students grow, succeed and make their own mark in the field brings me a sense of pride and accomplishment.

I aspire to continue pushing the boundaries of AI technology through innovative research projects that address critical challenges. Whether it is developing more robust and explainable AI algorithms, exploring the ethical implications of AI, or leveraging AI for social good, I aim to contribute to the development of AI solutions that benefit individuals and communities.

I aspire to advocate for and actively work towards increasing representation of women and underrepresented groups in the field. By promoting diversity in perspectives, experiences, and backgrounds, I believe we can develop AI technologies that are more inclusive, unbiased and aligned with societal needs.



Meet *Hadi*

From a young age, I was naturally drawn to mathematics and science. I found joy in deciphering complex concepts and unravelling the inner mechanism of systems. As I grew older, this passion evolved into a deep fascination with technology and its potential to transform society. Electrical engineering emerged as the ideal path for me to explore this passion further and contribute to the advancement of technology-driven solutions.

Throughout my academic journey, I have sought opportunities to enhance my engineering skills and broaden my knowledge. I have participated in research projects and internships which have provided me with invaluable hands-on experience and exposure to real-world engineering problems.

The focus of my PhD thesis is on developing novel deep-learning methods for processing temporal data, such as videos and physiological signals. My personal belief is that, currently, there is a gap between the theoretical development of novel deep-learning methods and their applications in real-life, and my personal goal is to fill this gap to the best of my ability.

When you have a passion for your job, it becomes more than just a means of earning a living. It fuels your motivation, creativity and dedication. Being genuinely interested in your work allows you to approach tasks with enthusiasm and a positive mindset. It enables you to invest time and effort in continuous learning and growth within your field, ultimately leading to improved performance and success.

In today's fast-paced and competitive world, being attentive to timelines is of paramount importance. Meeting deadlines is a sign of reliability and demonstrates your ability to manage your time effectively. Consistency is another vital attribute that helps build a reputation for reliability and dependability.

I take pride in the fact that my research projects have translated into tangible outcomes and have been disseminated to the scientific community through the publication of research papers.

My goal is to drive innovation and develop breakthrough technologies that have a significant positive impact on society. I aim to lead and mentor the next generation of signal-processing professionals, inspiring them to push the boundaries of knowledge and make groundbreaking contributions to the field.

Meet *Khanh*

My enthusiasm for electrical and computer research first took root when I received a scholarship to do an internship at the Machine Learning and Vision Lab at the Gwangju Institute of Science and Technology in South Korea. During that internship, I had a great opportunity to participate in an inspirational international conference held in Japan. Since then, I have been passionate about becoming a ML scientist who can develop effective AI algorithms to address many challenges existing in the biomedical field.

I am hard-working, passionate and self-motivated to pursue my research goal of developing ML algorithms to tackle biomedical challenges. I am always open to new and innovative ideas, which inspires me to push the boundaries of my current research.

I have been selected to become a Vanier scholar, a prestigious and highly competitive scholarship for doctoral students in Canada. Being a Vanier scholar, I will use financial resources to support my PhD study and connect with other researchers in the field.

I would like to become a ML scientist to develop effective algorithms for identification of a variety of disorders. Although I believe that ML cannot replace medical experts on a large scale, it can provide valuable findings that can help them in the diagnosis and treatments of diseases and disorders.

Introducing the free bioscience and biotech education initiatives supported by the Amgen Foundation

Established by Amgen, one of the world's leading biotechnology companies, the **Amgen Foundation** is committed to advancing excellence in science education and making a difference in Amgen communities. The Foundation's president, **Scott Heimlich**, describes how its four core philanthropic initiatives are having a lasting, positive impact on teachers and students.

Why was the Amgen Foundation set up?

Amgen was founded over 40 years ago, and the Amgen Foundation over 30 years ago. So, Amgen's commitment to serving patients, and our commitment to making a difference in our communities through philanthropy, has been core to who we are for decades. The Foundation started out by making grants in our local headquarters community, just as many corporate foundations do, but, today, we support initiatives in Amgen communities and beyond across the globe. Our goal – in alignment with our mission – is for the Amgen Foundation to reach as many people as possible through the nonprofits we support, both locally and worldwide.

What is the Foundation's mission?

While central to our mission is strengthening the communities where Amgen staff live and work, our ambition is to lead by making a difference at a larger scale, particularly where the need is greatest. The biopharmaceutical industry requires a highly educated scientific workforce, but we know that today's workforce doesn't represent all segments of society. Just look at past Nobel Prize winners in Medicine or Chemistry and the breakdown of those winners by gender or race or nationality; the numbers are way off. For instance, less than 3% of Nobel science winners are women, and only one woman of colour has received the award. Talent is universal, yet opportunity is not. Knowing this, we want to inspire more young people across the world to consider a career in science, and create more opportunities to meaningfully engage and prepare them. We firmly believe that everyone needs science, and science needs everyone.

The Amgen Biotech Experience (ABE) empowers teachers to bring biotechnology into their classrooms.
© Amgen Foundation

Why is science literacy an integral part of this mission?

Not only does our industry rely on a highly educated workforce, but biotechnology will also better achieve its full potential with a scientifically literate population. We need to support more people to understand and appreciate the role of science and biotech in our lives. Whether one is talking about the importance of vaccines, enrolling in clinical trials, or the significance of supporting basic research, a higher level of scientific literacy as well as a greater understanding of how medicines go from the bench to the bedside is critical to so many aspects of our lives.

How do teachers find the time to include the Amgen Foundation's resources in their science curriculums?

It's true that many teachers are crunched for time, but once they learn more about what the Foundation supports and has to offer, there's often an understanding of just how valuable a tool this can be for them and their students. Importantly, I'm referring to programmes that were created by and for teachers – with industry input – and that teachers opt in to engage with because they see the value. Take the Amgen Biotech Experience, for example. It's an opportunity for teachers to experience a professional learning opportunity right in their

The Amgen Foundation is on a mission to break down barriers and bring science education to everyone, everywhere, through its support of large-scale initiatives such as LabXchange. © Amgen Foundation

own community, meet other peer teachers who are already implementing the biotech labs with their students, and access free equipment and resources to engage their classrooms in the labs. Once teachers take these steps and see their students' reactions and the skills gained, it becomes less about 'how do I possibly fit this in?' and more about 'I'm going to fit this in because my students will really gain from this experience, and the programme staff will support me in doing so'.

Originally, the Amgen Biotech Experience was designed for US classrooms, but through our discussion and engagement to localise the programme with partners worldwide, we now support teachers to run these labs in 16 countries (and 27 communities) across the globe, including our US communities and countries such as Türkiye, Ireland, Germany, France, Japan and Mexico. There's a real hunger for initiatives that meaningfully engage students in hands-on science, and we are proud to have made possible such a rich and vibrant community of teachers, lab technicians and other stakeholders across the world.

How does LabXchange complement the Amgen Biotech Experience?

LabXchange has several virtual assets that both complement and supplement the hands-on labs. Our aim is to integrate hands-on and virtual learning to achieve the best learning outcomes possible. You can learn more by visiting the Amgen Biotech Experience section on LabXchange: **abe.labxchange.org**. Note that the Foundational Concepts and Techniques in Biotech content is available in 14 languages, including English, Spanish, French, Arabic and many others. And, new to the programme, the Exploring Precision Medicine labs can be found here: **www.labxchange.org/library/clusters/lx-cluster:lxc-pm**

How is the Foundation reimagining science education?

At the heart of what we do is to reimagine education so that anybody, regardless of their class, gender, race or other characteristics, has the opportunity to meaningfully engage in science.

Let's say there was such a thing as the Universe Olympics, and we had to foster the best swimming team on planet Earth. That team today would mainly comprise individuals from select nations because that is where the infrastructure and opportunity to practise swimming in pools currently are; in other words, we're only reaching a fraction of the potential population of swimmers, and we're certainly missing out on some of the very best who never had access in the first place. That same analogy can be applied

> ***"Talent is universal, yet opportunity is not. Knowing this, we want to inspire more young people across the world to consider a career in science, and create more opportunities to meaningfully engage and prepare them."***

The Amgen Scholars Program enables undergraduate students to participate in cutting-edge summer research opportunities at world-class institutions. © Amgen Foundation.

to science and, in particular, the discovery and development of new medicines. Due to lack of access and opportunity for too many people, there are aspiring scientists who simply never get the chance to engage authentically with scientific discovery. This doesn't just hurt them, this hurts all of us, as medicines are not discovered and developed, and ultimately patients are not treated. So, we are committed to widening the net with our initiatives by democratising access to the best in science education, both in-person and virtually.

Can you provide some examples?

We've invested over $40 million in the Amgen Biotech Experience, which has reached nearly one million students to date over three decades. We've donated over $70 million to the Amgen Scholars Programme, through which world-class universities host college students for a summer research experience. Through the Scholars programme, 5,300 students have participated to date from over 900 colleges and universities. And through a commitment of over $40 million to LabXchange, over 35 million users have accessed this science learning platform, with 85% of these users hailing from countries classified as low or lower-middle income by the World Bank. Tens of millions of people are also using the engaging biology content we've been proud to support Khan Academy to develop since 2015.

Our job is to not only make these opportunities and resources high-quality, but to keep them cost-free and accessible. Normally, you would expect to pay for things that are the best, but wouldn't it be ideal if some of the best educational content was free for all.

In your view, what are the essential skills that young people need to thrive?

Communication, collaboration, critical thinking, creativity and curiosity are all essential and much spoken about it in today's day and age. Of course, core disciplinary knowledge and hard skills like science and maths will never lose their importance, but intangible skills such as the aforementioned are integral to adapting to inevitable changes, especially with the arrival of AI. In fact, being adaptable and being a life-long learner will always be key to future success.

Discover key initiatives made possible by the Amgen Foundation

Amgen Biotech Experience (ABE): A free science education and professional development programme that supports teachers around the world with high-quality professional learning experiences, implementation resources and access to a global community. Established in 1990, the aim of ABE is to engage high-school students in real-world bioscience and biotechnological lab experiences. Available in 16 countries, ABE offers lab-based, classroom-based and virtual investigations. Teachers also have access to research-grade equipment free of charge.

www.amgenbiotechexperience.com www.amgenfoundation.org/science-education/amgen-biotech-experience

LabXchange: A free, online science learning platform aimed at middle school, high school and university teachers and students all over the world. Its curated library currently holds more than 20,000 resources from over 150 collaborating organisations, some of which are available in 14 languages. Created at Harvard University with support from the Amgen Foundation, this powerful digital tool makes high-quality science education accessible and gives learners and educators, everywhere, the courage to chart a meaningful path in science — for free.

www.labxchange.org www.amgenfoundation.org/science-education/LabXchange

Amgen Scholars: An undergraduate summer research experience hosted at 24 world-class educational and research institutions across the US, Europe, Asia, Australia and Canada. Through the programme, participants meet peers, present their research findings, learn about biotechnology and hear from leading scientists. Financial support is a critical component, ensuring that eligible students, regardless of income, can participate.

www.amgenscholars.com www.amgenfoundation.org/science-education/amgen-scholars-program

Khan Academy: A non-profit organisation founded in 2007 with a mission to provide a free, first-class education for anyone, anywhere. Since 2015, the Amgen Foundation has sponsored Khan Academy's online biology resources aimed at middle school, high school and college students.

www.khanacademy.org www.amgenfoundation.org/science-education/khan-academy

Find out more:
www.amgenfoundation.org
www.linkedin.com/company/amgen-foundation-inc

> ***I aspire to have the biggest impact I can possibly have, and this role allows me to be part of a team, an organisation and a company that's focused on doing just that.***

Meet Scott

My background is in education. After my bachelor's degree, I taught at a junior high school in rural Japan for a year, as part of the Japan Exchange and Teaching programme (JET). When I came back to the US, I completed my master's and doctorate degrees in education at the University of California, Los Angeles (UCLA). I worked for multiple higher education institutions before joining Amgen.

I always had an interest in education, government and the non-profit sector, but I would never have guessed that I'd work for the philanthropic arm of a company focused on making a difference in education. Growing up, I honestly didn't know much about corporate philanthropy. But being at a company that takes philanthropy as seriously as it does, and which set up and funds a foundation to make a real difference in the world through big, focused bets, has been, and continues to be, inspiring.

I aspire to have the biggest impact I can possibly have, and this role allows me to be part of a team, an organisation and a company that's focused on doing just that. Too often, corporate philanthropy can be looked at as PR-driven. That is not the case at many companies nor at the Amgen Foundation, where we lead with substance and focus on long-term focused and strategic giving in alignment with our mission. We're also proud to engage thousands of our staff members who give their time, talent and resources to joining the Foundation in making a difference. The Foundation has given over $425 million to date to support non-profits large and small across the US and the world – such efforts have enabled us to reach tens of millions of people and to dramatically improve lives.

That said, you certainly don't need to be the head of a foundation to make a big difference. People are making an incredible difference tutoring a student, serving on a non-profit board, writing a book. As an example, *The Ministry for the Future* by Kim Stanley Robinson is an eye-opening book portraying how climate change will affect us all – think of the difference a novel such as that will make should it reach a wide audience.

When you are starting out, it's always a good idea to consider trying something new. Even if you end up hating whatever it is you're doing, or wherever it is you're living, you'll be better off in the long run for having tried something

Science teachers engage in robust professional development opportunities supported by the Amgen Foundation. © Amgen Foundation

© Amgen Foundation

and expanded your horizon of what's possible. I remember hearing someone tell a student in California that they would hate going to a college in the northeast because it's much colder there, so that student didn't end up going and stayed in their hometown to attend college. Maybe it worked out great, but that's not the advice I would have given (assuming the student had the scholarship support to go out-of-state).

To get where you want to go, you have to know where you're going. Thinking about what you want to do, going for it, trying new things and not leaving it to chance is important. At the same time, if you're so rigid in what you want to do, opportunities can end up escaping you. A level of adaptability, openness and calculated risk-taking is so integral in today's world. A wonderful professor at UCSF used to cite a great quote from the literary critic Andre Gide: "One does not discover new lands without consenting to lose sight of the shore for a very long time."

One of the best pieces of advice I received is once you make a tough decision, make it the right one. This came from my mentor, Professor Bruce Barbee at UCLA, who we lost about a year ago – but not before he made a difference in the lives of countless students, including me.

Connect with Scott

linkedin.com/in/scott-heimlich

Plant polymers as plastic alternatives

Plastics are cheap and versatile but have a long-lasting environmental impact, and the race is on to roll out effective alternatives. **Professor Jeffrey Catchmark** and his team at **Pennsylvania State University** in the US believe they have one such solution, using common plant-based materials to create sustainable food packaging.

Professor Jeffrey Catchmark

Department of Agricultural and Biological Engineering, Pennsylvania State University, USA

PROFILE

Field of research
Biological Engineering

Research project
Developing a sustainable alternative to plastic paperboard coatings, using readily-available plant polymers

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

Talk like a ...

biological engineer

Biological engineering — a scientific field that combines the principles of biology and the tools of engineering to create useful products

Cellulose — a polysaccharide that gives structure to plant cell walls and vegetable fibres

Polymer — a substance with a molecule structure consisting (at least mostly) of many similar units bonded together

Polysaccharide — an organic substance with a large number of sugar molecules bonded together

Starch — a polysaccharide found in cereals and potatoes, functioning as a carbohydrate store

Plastics revolutionised the world, creating a vast array of materials that greatly expanded what people could produce and distribute. However, they carry a heavy toll: plastics require fossil fuels to be produced, and their longevity means that they can continue to exist for thousands of years into the future. This makes plastics a major source of pollution, and there is a global drive to reduce their production and use.

Based at Pennsylvania State University, Professor Jeffrey Catchmark and his team are addressing the key question of which materials could replace plastics. They are focusing on one application in particular – the use of plastic coatings within food packaging. For instance, a sandwich might be sold in a paperboard package with a plastic-coated inner side, which keeps the food fresh and stops water and oils from permeating but prevents the packaging from being effectively recycled or biodegraded. Jeffrey's team is developing a plant-based alternative to this product that solves this issue.

Plant matters

"We are focusing on a class of molecules known as polysaccharides, which are polymers of sugars," says Jeffrey. "They are typically derived from plants." The most abundant plant polysaccharides are cellulose and starch, and these two materials form the focus of Jeffrey's work. "Cellulose is primarily extracted from wood, while starch is extracted from corn, potato, cassava, rice or wheat," says Jeffrey. "Millions of tonnes of these polymers are produced commercially every year." Jeffrey's team has combined different types of celluloses and starches to form a coating on paperboard that has the same liquid-resistant properties as plastic but can also be composted.

"Our new technology eliminates the need for unsustainable plastic and fluorine coatings in many applications, reducing pollution and human health hazards," explains Jeffrey. "The materials also cost less than plastic, require no new equipment, and use existing production technologies." Given that cellulose production is already a big industry, Jeffrey is positive that this can provide the raw material needed to displace a large proportion of plastic production. "The coating can also be recycled with the paperboard, but if it ends up elsewhere, it will naturally degrade with no harmful impact on the ecosystem," he says.

From lab to factory

How does such a product come into existence? "The first step is the vision," says Jeffrey. His team began its research with the end goal of creating a sustainable and practical alternative to plastic packaging. "From


© Iryna Mylinska/Shutterstock.com

the vision comes a strategy," Jeffrey continues. "We focused on the lowest-cost, highest-volume sustainable polymers out there: celluloses and starches. Next came innovation." The main breakthrough came when the team explored the use of oppositely-charged polysaccharides. The combination of positive and negative charges created attraction between the long molecules, giving the composite materials the stability that was needed for manufacturing.

"We created many formulations and tested to industry standards so that companies would understand the performance of our product and the opportunities it granted," explains Jeffrey. In fact, the team worked with nearly 30 companies to fine-tune its coating formulation for different packaging types. "We learned something new from each company, and each product application posed a new challenge," Jeffrey says. "Discovering how to translate technologies developed in the lab into products that make a real difference is really exciting." One big lesson from across all companies was that change is difficult. It became clear that to make such transitions more likely, processes had to be easily manufacturable, using readily-available materials that are familiar to the industry.

> **"Discovering how to translate technologies developed in the lab into products that make a real difference is really exciting."**

Rising to challenges

A major challenge for the team was accounting for the different timescales between labs and production companies. "We had to work hard to keep up with company needs," says Jeffrey. "Often, the specifications would shift as we were in development." With these lessons learnt, the team is now setting up a company which will have the resources and flexibility to work with other companies on short timescales.


Cellulose fibers, microscope image
© Henri Koskinen/Shutterstock.com

Another challenge involved negotiating with cellulose and starch suppliers. "The suppliers are usually interested in selling tonnes of material, not the pounds we need for trials," says Jeffrey. "Creating positive relationships was key to overcoming this!" While the team does not buy much raw material, if its packaging solution is well-received, the suppliers could see a jump in demand for their product from manufacturers. Convincing suppliers of this outcome is an effective way to get them on board.

"We hope to have this product on the market within a year," says Jeffrey. "But our research won't stop there. We aim to continue making our product even more sustainable." The team will be investigating how to manufacture the plant-based packaging using fewer resources and chemicals, less energy, and with an eye on any other socio-ecological impacts.


© Ground Picture/Shutterstock.com

About *biological engineering*

Biological engineering integrates concepts from life sciences with practices from engineering. Its scope is huge, ranging from the engineering of molecules through to entire ecosystems. Jeffrey's work focuses on the micro scale, engineering naturally occurring molecules into products with useful commercial properties. In particular, the products provide sustainable alternatives to polluting materials. Jeffrey explains more about his career and field.

"Biological engineering is one of the most exciting disciplines out there. It involves understanding and manipulating living systems and the things these systems produce. Traditionally, it has focused on areas like agriculture and biomedicine, but it has since become much broader. Nowadays, it encompasses artificial intelligence (AI), the brain-computer interface, synthetic biology, and even social and ethical analysis.

"Biological engineers are engineering life. In some cases, this means genetically engineering a microbe or plant and, in others, can mean engineering a food production process, a sustainable wastewater system, or a robotic limb that connects to a person's brain. I believe biological engineers may have more impact on the technology that shapes humanity and our environment than any other discipline.

"For 10 years, I have been involved in ethics education and ethical organisational management, and I want to spend more time in this area. I strongly believe that the world needs engineers with strong critical thinking skills, who know how to ask questions, understand bias, construct and evaluate arguments, and think comprehensively and creatively. This goes hand in hand with ethical thinking. There are ethical aspects to everything we do, and we need to understand our own values and the values of others to make good decisions.

"If you're interested in biological engineering, I recommend getting to know some biological engineers and understanding what they do. This can include asking how they prepared for their career, what made them successful, what drives them, and what they find challenging. You can start at your local university or via engineering societies and organisations. Find out what excites you and keep asking questions!"

Jeffrey's *top tip*

Ask yourself about yourself. What are your values? Where did they come from? What contributions do you want to make to the world? How are you developing and addressing both your strengths and weaknesses? What energises you? What are your near-term and long-term goals? Once you have a better understanding of yourself, you can start planning your next steps.

© VICUSCHKA/Shutterstock.com

Pathway from school to *biological engineering*

Jeffrey says that biological engineering entails a robust understanding in maths, physics, chemistry and biology. He also emphasises that the world needs responsible engineering leaders and suggests developing skills in critical thinking and ethical thinking, such as through classes in philosophy, ethics, history, sociology, psychology or politics.

Explore careers in *biological engineering*

- The Institute of Biological Engineering's 'Ask an Expert' feature is specifically designed for learners to receive answers to their questions from biological engineering experts: **www.cognitoforms.com/AgentisManagement1/AskAnExpert**
- Pathways to Science contains a directory of internship opportunities for different STEM fields. You can find internships relevant to biological engineering: **www.pathwaystoscience.org/discipline.aspx?sort=ENG-Bioengineering_Bioengineering#High%20School%20Students**
- According to PayScale, the average salary for a biological engineer in the US was around $74,500 in 2023.

Meet *the team*

Caini Chen
PhD Graduate Assistant

I have always loved unravelling complex challenges. The idea of being able to apply scientific knowledge to address real-world problems captivates me. I followed an engineering major and then pursued biological engineering, aiming for a career that not only satisfies my passion for problem solving but also aligns with my core values.

As a student of Dr Catchmark, I have developed a strong sense of ethical awareness. This is an important attribute for everyone, no matter what career you are in.

Another attribute that has shaped me as a scientist is my passion for learning. I am always seeking opportunities to learn. This has helped me to think outside of the box when I am facing intricate problems, and it has also helped me to stay curious and open-minded about the world.

During my senior year of undergraduate studies, I took a class with Dr Catchmark, and I soon decided to pursue a PhD under his guidance. It is hard to find an advisor who not only inspires you academically but also imparts invaluable life lessons. Under his mentorship, I have not only evolved into a better researcher but also a better person.

I am currently working as our lab manager. One of the primary tasks for me is to order necessary supplies for the lab and maintain an organised inventory system to prevent any delays in research activities.

The highlight of this research for me is successfully transitioning the lab-scale product to the commercialisation stage. This paves the way for its use among the general public in the near future. Witnessing the process of transforming a concept into a tangible reality that could benefit countless individuals has been an incredibly meaningful experience, reinforcing my commitment to advancing scientific knowledge and fostering innovation.

My aim is to establish my own company, developing affordable sustainable materials.

Parisa Nazemi Ashani
PhD Graduate Assistant

I pursued a PhD in biological engineering after studying chemical engineering and working on biofuels. My passion for protecting the environment led me to explore other sustainable materials and processes. I'm committed to making a positive impact on our planet through innovative research and collaboration, pushing the boundaries of what's possible in the field.

I love mathematics, problem solving and logical thinking. This interest and great mentors motivated me to study a STEM major, learn critical thinking and become a scientist.

In Dr Catchmark's lab, we prioritise sustainability without compromising quality. I am motivated to contribute to a better future, aligning my aspirations with the lab's mission to create eco-friendly solutions with a positive impact.

As the most experienced PhD student in the lab, my role involves mentoring and training other students. Our group fosters a culture of collaboration, sharing research questions and exploring solutions together. **The highlight of this research is its incredible potential for diverse applications.** Working on solutions with tangible results has been the most joyous aspect of my academic career, and it's rewarding to know that our efforts will soon translate into practical applications.

Dr Wei-Shu Lin and I have also collaborated with the Chesapeake Bay Foundation and Plantra to devise a plant-based, sustainable grow tube to replace the plastic grow tubes being used by Pennsylvania's Keystone 10 Million Trees Partnership.

My ambitions revolve around this type of environmental stewardship. I am determined to play an active role in reversing the detrimental impact of human actions on the environment.

Dr Wei-Shu Lin
PhD Graduate Assistant

My initial major was in wood science. My home country boasts a vast forested area, and I wanted to contribute to my country's sustainable development. However, my curiosity led me to delve into sustainable materials beyond the realm of wood-based resources, which led me to biological engineering.

The first time I worked in a lab, I learnt how to synthesise a resin with wood-based ingredients. Creating something from nothing made me want to create something the world needs.

As an undergraduate student, I focused on studying sustainable materials, modifying traditional resins to enhance their biodegradability. I then joined Dr Catchmark's lab, as his work centres around natural fibre-based materials – a field that has always captivated my interest.

Upon joining the lab, I found myself as the sole PhD student, which meant taking on the responsibility of mentoring incoming junior students and guiding them on their academic journeys. My role involved helping them get acclimatised to their studies and setting them on the right path for success.

The highlights of this research journey have been truly remarkable. While the concept itself may not be new, our unique approach transformed it into an entirely novel application. The most rewarding aspect is realising that this unexplored avenue has ignited curiosity and interest among individuals who previously hadn't considered the possibilities it presents.

My proudest career achievement is the 10 Million Trees project I undertook with Parisa. I am particularly proud that our idea successfully progressed to the next stage of prototype development, solidifying our commitment to making a positive impact through sustainable solutions. This experience has further reinforced my dedication to creating a greener and more sustainable future.

How do bacteria help and harm crops?

Over half of the world's population depends on rice as a staple food. However, some bacteria cause diseases that can drastically reduce rice harvests, potentially leading to famine. Meanwhile, other bacteria are beneficial for soybean plants, as they help produce important nutrients. Understanding how bacteria interact with plants is, therefore, essential for preventing plant disease and increasing crop yields. This is why, at **Louisiana State University** in the US, **Professor Jong Hyun Ham** is studying the impacts of bacteria on rice and soybean.

Professor Jong Hyun Ham

Department of Plant Pathology and Crop Physiology, Louisiana State University Agricultural Center, USA

PROFILE

Fields of research
Plant Pathology, Phytobacteriology

Research project
Investigating the harmful and beneficial impacts bacteria have on rice and soybean

Funders
US Department of Agriculture – National Institute of Food and Agriculture (USDA-NIFA), Louisiana Rice Research Board, Louisiana Soybean and Grain Research and Promotion Board

Talk like a ...

plant pathologist

Bacterial panicle blight (BPB) — a disease caused by the bacterium, *Burkholderia glumae*, that attacks the panicles of rice plants, resulting in severely reduced crop yields

Genome — the complete set of genetic material in an organism

Legume — a plant from the family that produces seeds in pods, such as soybean, pea, bean and lentil

Microbe — a microscopic organism, such as a bacterium

Panicle — a branching cluster of flowers

Pathogen — a microbe that causes disease

Pathology — the study of diseases

Quorum-sensing — a form of cell-to-cell communication between bacteria

Recombinant DNA technology — the laboratory technique by which DNA molecules are broken apart and recombined

Symbiotic relationship — a close and mutually beneficial interaction between two organisms

Transposon — a segment of DNA that can be inserted into a gene

Virulence — the harmfulness of a pathogen

Rice and soybean are, respectively, the most important cereal and legume crops worldwide. "Over 50% of the world's population depends on rice as a staple food," says Professor Jong Hyun Ham, a plant pathologist at Louisiana State University. "It is also an important source of high-quality nutrients, especially to low-income people in developing countries, so its contribution to global food security is invaluable." Soybean is a high-energy, high-protein crop that is indispensable as animal feed. Over three quarters of global soybean production is fed to animals, with the remainder used for tofu and soy milk for human consumption or converted into biofuels and petrochemical alternatives for industrial purposes.

How do soybean and rice interact with microbes?

Healthy soil is teaming with life. In fact, there about one billion microbes in just one teaspoon of soil! When these microbes interact with plants, the interactions may be beneficial, harmful or have no effect on the plant. Therefore, plant pathologists like Jong need to learn as much as possible about how plants and microbes interact with each other at the molecular level, to understand which interactions may lead to crop disease, how pathogens attack plants in these cases, and how the plants defend themselves. With this knowledge, scientists can develop disease-resistant crop varieties and other disease control strategies.

Soybean, like other legumes, has a symbiotic relationship with bacteria that live on the soybean roots. These bacteria are beneficial to the plant, as they convert nitrogen gas in the atmosphere into ammonium, a nutrient essential for plant growth. On the other hand, the bacterium *Burkholderia glumae (B. glumae)* has a harmful effect on rice as

Lab members grow rice and soybean plants in the greenhouse to investigate their interactions with harmful and beneficial bacteria

it causes bacterial panicle blight (BPB), a serious crop disease. The pathogen attacks the panicles of the rice plant, preventing the rice grains from developing. BPB can severely damage rice crops, reducing yields by up to 80%.

"Unfortunately, most of the popular rice varieties grown around the world are susceptible to BPB, and effective tools to control the disease, such as chemical products, are rarely available," says Jong. "Thus, it is imperative to develop innovative strategies to control BPB based on better knowledge of the rice-bacteria interactions underlying it."

What molecular techniques is Jong using to study *B. glumae*?

Jong and his team use various tools and techniques from molecular biology and genetics to study *B. glumae* and its interactions with rice. The genome of *B. glumae* contains thousands of genes, and Jong needed to discover which ones contribute to the bacterium's virulence, or ability to harm rice plants, which it does by producing the toxin, toxoflavin. To do this, the team used a molecular biological tool known as transposon, a segment of DNA that can be inserted into the bacterial genome.

"Scientists can introduce transposon into a bacterial cell, where it will 'jump' into a gene in a random way, disrupting that gene's genetic function," explains Jong. "Using this characteristic of transposon, we generated a collection of mutants for almost every gene of *B. glumae*, except for the ones essential for the bacterium's survival."

Jong and the team then analysed all the mutant bacteria to determine whether they were producing more or less toxoflavin, which indicated whether they were more or less virulent than normal. "In other words, we examined whether toxin production was changed due to the disruption of the gene by transposon, indicating that that gene is important for toxoflavin production," explains Jong. "The genes responsible for the altered virulence could be traced and identified from the transposon inserted in them."

> **"It is imperative to develop innovative strategies to control bacterial panicle blight based on better knowledge of the rice-bacteria interactions underlying it."**

In addition, the team used recombinant DNA technology to delete certain genes from *B. glumae*, then observed how the bacterium functioned without them. If a mutated *B. glumae* had altered virulence, it suggested that the deleted gene played a role in controlling the bacterium's virulence.

The team also studied the social behaviours, or collective actions, of *B. glumae*, as these interactions are important for understanding how BPB develops. Social behaviours of bacteria are determined by cell-to-cell communication, known as quorum-sensing, so Jong mutated different genes involved in cell signalling to examine which controlled *B. glumae* quorum-sensing.

What has Jong discovered about *B. glumae*?

Jong and his team have had great success investigating the biology of *B. glumae* and its impacts on rice. They have discovered five new genes that control the virulence of *B. glumae*, determined that the widely accepted model of *B. glumae* quorum-sensing was incorrect, and uncovered a key regulatory factor of *B. glumae* that determines its ability to cause BPB. "Because *B. glumae* cannot cause BPB without this regulatory factor, our next research direction is to find the chemical compounds and physiological conditions that can disable its function," explains Jong.

How is Jong contributing to the development of disease-resistant crops?

As well as studying the bacterium itself, Jong and his team are investigating the genes in rice plants that prevent them developing BPB when exposed to *B. glumae*. Using genetic techniques, they have identified the location of disease-resistant genes on the rice genome and uncovered the DNA differences associated with disease resistance. "We have found and characterised several new genetic elements associated with rice disease resistance to BPB," says Jong. "We have also developed numerous rice lines showing improved disease resistance to BPB."

The team has characterised the molecular pathways that allow rice and soybean plants to resist bacterial diseases. However, not all plant-bacteria interactions are harmful to crops. Jong's research is also focused on the beneficial interactions that could improve rice and soybean crop yields. "We have identified numerous beneficial bacterial organisms from various environmental conditions through multiple rounds of laboratory and greenhouse tests," he explains. "These biological materials are the main focus of our research activities to formulate new products to enhance the growth and health of rice and soybean." In addition to these beneficial bacteria, the team has successfully identified biochemical materials that, when applied to rice and soybean seeds, promote their growth and increase the disease resistance of the plants.

Thanks to the efforts of plant pathologists such as Jong, scientists are developing a better understanding of how to protect key crops from bacterial disease, and how to use beneficial bacterial to increase crop yields, hopefully resulting in improved global food security.

About *plant pathology*

Plant pathologists study plant diseases and develop new ways to prevent, treat and manage them. These researchers are hugely important for addressing global issues such as food security and food safety. "Historically, plant diseases have had tremendous impacts on human society," says Jong. "For example, 'The Great Famine' in Ireland during the mid-1800s was caused by potato disease, while the Bengal famine in India in 1943 was due to an outbreak of rice brown spot disease." Plant pathologists across the globe are working in laboratories, greenhouses and fields to prevent and reduce the loss of life and economic impacts caused by plant diseases such as these. "I hope my research on bacterial pathogens and the genetics of rice disease resistance will lead to the development of more resistant rice varieties," says Jong. "And I hope my research on beneficial bacteria will provide insights for the development of innovative disease management strategies for rice and soybean diseases."

A day in the life of a plant pathologist

As a professor of plant pathology, Jong spends his time reading to learn more about the molecular mechanisms behind plant diseases, writing grant proposals to get more funding for his research, writing up the results of his work to share them with the scientific community and meeting with his team members to discuss their research projects. He also visits the team's greenhouses and fields to monitor the plants growing there and conducts genetic experiments and molecular analyses in the laboratory.

What are the joys and challenges of the job?

"A great joy for me is discovering new things about the microbial world surrounding crop plants and plant defence systems," says Jong. "I also enjoy meeting my laboratory members every morning to discuss our research projects and science in general." But being a plant pathologist is not without its difficulties. "Unpredictable weather conditions are the most challenging part of field experiments," says Jong. "We must also deal with various technical problems that occur during our laboratory research."

Pathway from school to *plant pathology*

- As well as studying biology and chemistry at school, try to get practical experience of working with plants. If there is a local gardening group, botanical garden or horticultural society in your area, contact them to see how you could get involved to learn more about plant science.
- Contact the agriculture or biology departments at local universities to find out if they offer outreach opportunities for high school students. For example, Jong's department at the LSU AgCenter runs youth development programmes that introduce students to agricultural skills and research: **www.lsuagcenter.com/topics/kids_teens/programs**
- At college or university, a degree in plant pathology, plant science, botany, agricultural science or horticulture could lead to a career in plant pathology. "Microbiology, genetics and biochemistry are essential subjects for understanding the principles of plant pathology," says Jong, so take any courses offered in these areas. "Analytical chemistry, statistics, plant physiology, plant anatomy and organic chemistry are also strongly recommended if you want to conduct plant pathology research."
- The American Phytopathological Society (APS) has a huge range of educational resources (**www.apsnet.org/edcenter/foreducators**), including information about different plant diseases, activities to try in class, a podcast (**www.plantopiapodcast.org**) and YouTube channel (**www.youtube.com/user/plantdisease**).

Explore careers in *plant pathology*

- As a plant pathologist, you could conduct experiments to uncover the molecular mechanisms behind plant diseases and develop disease-resistant crops at a university, for an agricultural biotechnology company or for a government agricultural agency.
- Learn more about the research conducted in the Department of Plant Pathology and Crop Physiology at Louisiana State University: **www.lsu.edu/agriculture/plant**
- The APS provides information about careers in plant pathology, including different roles in the field and advice from plant pathologists in different positions: **www.apsnet.org/careers/careersinplantpathology**
- Jong suggests visiting the websites of agricultural biotechnology companies such as Syngenta (**www.syngenta.com**), Corteva Agriscience (**www.corteva.com**) and Bayer (**www.bayer.com/en/agriculture**) to explore what they do. Many companies offer internships for students.
- The US Department of Agriculture (USDA) offers internships in different aspects of agricultural research: **www.usda.gov/youth/career**

Members of Jong's lab work in the rice field © John Ontoy

Meet *Jong*

When I was younger, I was interested in natural sciences, including physics, biology, astronomy and geology. I was concerned about the future of humankind due to the rising issues of global food security and environment protection. These interests and concerns led me to study plant pathology.

I was inspired to pursue a career in plant pathology thanks to the experiences I had during my undergraduate studies. During my first year in college, I took a course in microbiology where I became fascinated by the fact that plants get diseases caused by microbial pathogens, just like humans and animals. And, while working in research laboratories, I was amazed to see how the pretty-looking cultures of fungi and bacteria could cause severe symptoms for the plants they infected. Most importantly, I was blessed to have great teachers and mentors at the early stages of my career.

> ***I am happy that my work can help farmers produce crops in more economically efficient and environmentally friendly ways.***

I am proud that I am studying something very important but not very well known. Before studying plant pathology, I did not know that plants get sick from pathogen infections, or how severe the damages caused by epidemics of plant diseases can be. I am happy that my work can help farmers produce crops in more economically efficient and environmentally friendly ways. Moreover, it is a great pleasure to learn more about this world through studying how plants and microbes interact.

In my free time, I like reading and watching videos about physics, astronomy and philosophy. I also enjoy listening to and playing music, and at the weekend, I am actively involved in church activities.

Jong's *top tips*

1. Get a good morning routine. I try to start my day at the workplace an hour ahead of my colleagues. Shaping yourself as a morning person is important for working in a laboratory, greenhouse or field, and it will help your productivity regardless of the career you choose.

2. Never finish anything without going through a proper reflection process. You will not always be successful in your work, but whether something was successful or unsuccessful, you should make a proper, written record. Otherwise, your results will be forgotten, and your time and effort will become meaningless.

Engaging with the science behind food

The preparation of food is biochemically complex. At **North Carolina Agricultural and Technical State University** in the US, **Dr Salam A. Ibrahim** has established the **Food Microbiology and Biotechnology Lab**. Here, researchers and students collaborate with the food industry to address real-world challenges in food production and safety by uncovering the secrets of food microbiology. By providing students with opportunities to learn about and participate in food science research, the lab is also inspiring the next generation of food scientists.

Dr Salam A. Ibrahim

Food Microbiology and Biotechnology Lab, College of Agricultural and Environmental Sciences, North Carolina Agricultural and Technical State University, USA

Fields of research
Food Microbiology, Food Biotechnology, Dairy Food Technology

Research project
The Food Microbiology and Biotechnology Lab – combining discovery, education and outreach of food microbiology, safety and innovation

Funders
US Department of Agriculture National Institute of Food and Agriculture (USDA-NIFA), Department of Homeland Security (DHS).

This research was funded by a NIFA Evans-Allen grant (no. NC.X-267-5-12-170-1) and a NIFA capacity grant (no. 2022-38821-37351)

PROFILE

Talk like a ...

food microbiologist

Antimicrobial — something that kills or inhibits microorganisms

Bifidobacteria — a group of probiotic bacteria that live in the gut

Buffering capacity — the ability of a substance to resist changes to its pH

Fermentation — the chemical breakdown of a substance, often by bacteria or yeast

Growth medium — the substance on which bacteria are grown in a lab

Lactic acid bacteria — a diverse array of bacteria that ferment carbohydrates to produce lactic acid

Probiotic — a microorganism that stimulates the growth of beneficial gut bacteria

Eating is typically an enjoyable part of daily life. However, most people are probably unaware of the biochemical complexity of food and of what is involved in getting food safely from the farm to the table. In the Food Microbiology and Biotechnology Lab at North Carolina Agricultural and Technical State University (NC A&T), Dr Salam A. Ibrahim and his team explore these processes in depth, while cultivating a fascination with food from a scientific standpoint.

The lab is using state-of-the-art technology to improve the quality and safety of food products. Dr Ibrahim and his team collaborate with food industry professionals to learn about challenges they are facing and to develop innovative solutions to solve them. Then, they share their discoveries to educate the public and the next generation of food scientists. "Our strategy is based on the novel application of creative thinking and collaboration to achieve extraordinary outcomes," explains Dr Ibrahim. This process of discovery, education and outreach is key to the lab's many successes.

Discovery: exploring the benefits of bacteria

A key focus of the lab's research is understanding the role of bacteria in food. While bacteria commonly get bad press for causing illnesses, the human gut is home to millions of bacteria that are actively helping us. Dr Ibrahim and the team are studying how 'bad' bacteria damage food and cause safety concerns, and how 'good' bacteria improve human health.

Dairy products are a common source of probiotic cultures (microorganisms that keep the gut healthy) so Dr Ibrahim's team is exploring how these beneficial bacteria could be artificially added to other food products. "We've been trying to isolate strains of bifidobacteria and lactic acid bacteria, probiotics that could improve human health, food quality and food safety," explains Dr Ibrahim. "We're also investigating new methods to improve the function of probiotic supplements."

Probiotic bacteria have a range of health benefits, such as aiding digestion, protecting against infections, and even fighting cancer. "Recently, we started working with

Lactobacillus bulgaricus, a key bacterium in yoghurt production," says Dr Ibrahim. "We're interested in developing practical methods to produce this probiotic strain at the commercial scale."

Education: inspiring the next generation of food scientists

Students studying food science at NC A&T benefit from the Food Microbiology and Biotechnology Lab in many ways. Not only does Dr Ibrahim use the results of his research when teaching classes about food microbiology and food safety, but students can also work in the lab to gain experience conducting their own food science research projects.

"When I first joined the lab, I helped graduate students with their research by creating bacterial growth media and growing bacteria for their experiments," says Alaina Brock. "Now, I conduct my own research projects, focusing on using bacterial enzymes to discover new antimicrobials." Thanks to his research experiences in the lab, Philip Junior Yeboah has gained skills in microbiology, fermentation, food safety and food product development. "I've participated in numerous research activities, including determining the buffering capacity of different coffee samples, perfecting the optimal growth medium for bacteria, and developing sweet potato energy bars to take advantage of the abundance of sweet potatoes grown in North Carolina," he says.

Dr Ibrahim is keen to provide his students with experiences that enrich their education and prepare them for future careers in food science. "Our students have opportunities to work closely with the food industry, and to design research projects based on industry needs," he says. Guest speakers from local food companies and federal agencies, such as the US Department of Agriculture (USDA) and Food and Drug Administration (FDA), share their expertise with students, and students participate in field trips to contextualise their classroom learning in industry settings. Thanks to the unique multidisciplinary approach among research, teaching and outreach, Dr Ibrahim was also able to establish the Food Science and Technology Endowment Fund to provide financial support for students studying food and nutritional science degrees at NC A&T.

> ***"To be relevant, research depends upon understanding the needs of the industry and the wider world. I am interested in working with the food industry to provide solutions to real-world challenges."***

Outreach: connecting research with the real world

"To be relevant, research depends upon understanding the needs of the industry and the wider world," says Dr Ibrahim. "I am interested in working with the food industry to provide solutions to real-world challenges." To this end, the lab hosts unique partnerships with food companies and farmers. "Most of our research is a collaboration between the food industry, consumers and our research team," says Philip. "It is this collective approach that most often leads to breakthroughs."

Outreach is a two-way conversation. Food companies and farmers indicate the knowledge gaps in the food industry that need to be filled. In return, the Food Microbiology and Biotechnology Lab fills these gaps through rigorous scientific research. "The food industry continues to look for new ideas that have practical applications and low costs," explains Dr Ibrahim. "For example, the industry wanted to improve lactic acid bacteria growth to provide health benefits while using low-cost raw materials. We developed new approaches that have improved health benefits and reduced costs."

The lab has completed many successful research projects that are now having a positive impact on the food industry. For example, the team developed a growth medium that enhances production of bacterial cells and discovered how lactic acid bacteria produce natural antimicrobial compounds.

In addition to conducting research, students in the lab also participate in outreach activities to educate the public about food science and food safety. "On one occasion, we welcomed a class of high school students to the lab and gave them a tour of the facilities," recounts Alaina. "My favourite part of this activity was showing students how to measure the pH of different foods, and explaining what this means for their application in food products."

The team's research is also shared with local food producers and consumers. "We help train local farmers on issues related to food handling and safety," says Dr Ibrahim. "We support them in developing laboratory procedures to test their products and provide practical training workshops." The lab also runs a stall at the local farmers' market to provide information and interactive demonstrations about food safety for vendors and customers. "We demonstrate the importance of food preservation techniques, proper food handling practices and the nutritional benefits of various foods," says Philip. "A farmers' market is a dynamic, community-driven environment. By using our food science knowledge, we contribute to the market's success while empowering consumers and fostering a deeper appreciation for the science behind the food we eat."

Through this unique combination of discovery, education and outreach, the Food Microbiology and Biotechnology Lab is contributing to healthier, tastier and safer food by supporting the food industry and inspiring the next generation of food scientists.

About *food microbiology*

Food microbiology is the subfield of food science that studies the microorganisms involved in food. While some of these contaminate food, others are essential for its production. For example, although fluffy fungi and slimy moulds destroy foods and make them unsafe to eat, yoghurt production relies on *Lactobacillus bulgaricus* to ferment milk, and bread rises thanks to yeast fermentation.

Food safety is a key aspect of food science, relying on good hygiene and proper food preparation and storage. While food microbiologists are studying microorganisms to explore how to prevent them contaminating food, the easiest step to food safety is keeping everything clean – wash your hands before and after preparing food and eating, and keep all utensils clean.

Why study food science?

"Studying food science allows you to understand food scientifically," says Philip. "You will learn about food composition, preservation and the impact of processing techniques at a scientific level." And with so many areas within the field, there is a wealth of opportunities to tailor your studies and future career in whatever direction matches your interests. Do you enjoy cooking, experimenting with flavours and tasting new foods? Are you interested in understanding how the chemical compounds in different foods influence human health? Would you like a career in food safety, such as performing quality control while monitoring food production lines? Studying food science will open many doors for you. "Our students have a wide range of opportunities ahead of them," says Dr Ibrahim. "These include jobs with the food and food services industries, as well as careers in academia and government."

Dr Ibrahim is also passionate about the importance of interdisciplinarity within the Food Microbiology and Biotechnology Lab. "Every scientific discipline, from biology and chemistry to engineering and economics, contributes to our success in a different way," he says. "Food science, food safety and microbiology are all distinct, but related, interdisciplinary subject areas. The field of food science relies on leveraging knowledge from different disciplines alongside technological resources to enrich the research and learning process."

Pathway from school to *food microbiology*

- If your school offers classes in food science or food technology, take these to learn the basics of the science behind food.
- Dr Ibrahim also recommends studying biology, chemistry and mathematics to learn about microorganisms, chemical reactions and statistical analysis.
- At university, degrees in food science, food microbiology or related subjects (such as food technology or food and nutrition) could lead to a career in food microbiology.

Explore careers in *food microbiology*

- "There are many career paths in food microbiology, ranging from microbiology research and food engineering to food safety, quality assurance and product development," says Philip. "Careers in the sector are highly meaningful, as the world faces significant food security challenges. Jobs often combine scientific principles with practical applications, allowing the development of safe, nutritious and sustainable food while addressing global issues."
- "Everybody has to eat!" says Alaina. "This highlights the importance of food science and means the number of jobs available in the field, especially in food microbiology and food safety, is continuously increasing."
- Dr Ibrahim recommends joining the American Chemical Society, which provides opportunities for high school students, such as chemistry clubs, competitions, magazines and summer schools: **www.acs.org/education/students.html**
- Dr Ibrahim also recommends exploring the American Society for Microbiology, which provides a wealth of career resources for students: **www.asm.org/Careers/Career-Planning**
- Additionally, the Institute of Food Technologists (**www.ift.org**) and American Dairy Science Association (**www.adsa.org**) have resources specific to their respective sectors.

Meet members *of the Food Microbiology and Biotechnology Lab*

Alaina Brock
Undergraduate Research Scholar

I have always loved cooking – I used to bake cakes with my late grandmother and father. I began considering food science as a career after watching a TED Talk, 'The Chemistry of Cookies', by Stephanie Warren, that described bakers as mad scientists! The talk gave me a taste of the cool chemical reactions that occur in foods to create our favourite flavours.

After graduating, I hope to pursue a PhD in food science then work for a consumer products company developing snack foods. I believe that snacks should be both delicious and healthy, and I would love the opportunity to work with some of the brands that are cherished around the world.

My favourite concept within food science is the process behind Maillard reactions. These reactions happen when amino acids and sugars are exposed to heat, resulting in a variety of new molecules forming. It is these molecules that are responsible for all the wonderful tastes and aromas that we find in browned food, such as cookies, caramel and baked chicken.

To me, food science is a continuous source of interest as I love experimenting with new flavours and textures. It's also always fun to taste your work! I enjoy working in the Food Microbiology and Biotechnology Lab because it gives me the opportunity to gain relevant work experience in how to conduct scientific research, and I have met many researchers, students and mentors who have enriched my studies.

I received a fair few rejections when applying for opportunities in food science, but I didn't let this discourage me. If you are passionate about something, continue to put yourself out there and you will find your niche!

Alaina's *top tips*

1. Seek opportunities outside the classroom, such as work experience with food businesses, that will expose you to the basics of the food industry.
2. Consider which areas within food science most interest you, such as food microbiology, chemistry or safety.
3. Find connections with people who can support and mentor you through your studies and career, such as industry professionals and academic researchers. Such connections can provide you with valuable opportunities and advice.

Philip Junior Yeboah
Graduate Research Assistant

I have always had a passion for food, and I enjoy experimenting with ingredients and exploring different cuisines. I grew up in a farming household and developed a deep appreciation for the importance of food and its impact on society. My father's commitment to delivering high-quality products inspired me to learn about the principles of food safety.

I was intrigued by the scientific processes involved in transforming raw agricultural produce into food products. This fascination, combined with an interest in how food influences human health, motivated me to study food science. I have developed a passion for understanding the science behind food production, preservation and development, as well the importance of developing healthier food options to address health issues.

The field of food microbiology and biotechnology is constantly evolving. I enjoy working in the Food Microbiology and Biotechnology Lab because I have the opportunity to explore the intersection of food and science, including the microbiological aspects of food and how biotechnology can be applied to improve food safety, quality and production. As a student, it is satisfying to make significant contributions to ensuring food safety alongside my studies.

After achieving my master's degree, I hope to undertake a PhD in food science. Beyond that, I aspire to work in food science research, quality assurance or product development. I would like to develop new food products, improve the quality of existing ones and explore innovative food technologies. I also dream of starting my own food-related business. With a solid understanding of food science principles, I can innovate and develop unique food products, launch a food manufacturing company, or establish a consulting firm providing expertise to the food industry.

Philip's *top tips*

1. Seek practical experience through internships, research placements or volunteer opportunities in food-related industries. This will expose you to the real world of food science and provide valuable networking opportunities.
2. Pursue leadership roles and engage in related extracurricular activities. These will develop your teamwork, communication and organisational skills, while demonstrating your commitment and passion for the field.
3. Seek mentorship. Find mentors who can provide guidance, support and advice throughout your academic and professional journey.

Keep calm and carrot on: how can we breed better carrots?

The colourful carrot is one of America's favourite vegetables, but carrot farmers face many challenges when growing their crops. At the **US Department of Agriculture Vegetable Crop Research Unit** at the **University of Wisconsin-Madison**, USA, **Dr Bill Rolling** and **Dr Jenyne Loarca** are investigating what influences carrot germination and growth, helping plant breeders to cultivate more successful carrot varieties.

Dr Bill Rolling

Dr Jenyne Loarca

US Department of Agriculture Vegetable Crop Research Unit, Department of Horticulture, University of Wisconsin-Madison, USA

PROFILES

Fields of research
Plant Genetics, Plant Breeding

Research project
Investigating the factors that influence carrot germination and growth

Funder
This work is supported by the US Department of Agriculture National Institute of Food and Agriculture (USDA-NIFA), award number 5090-21000-069-061-I. The contents are solely the responsibility of the authors.

Talk like a ...

plant geneticist

Canopy cover — the area of ground shaded by a plant's leaves

Crop — a cultivated plant, often grown for food

Cultivar — a variety of a plant species that has been produced by selective breeding

DNA sequencing — the process of determining an organism's DNA

Food security — having sufficient nutritious food

Genotype — all the genetic material within an organism

Germination — when a seed begins to grow

Herbicide — weed killer

Phenotype — the physical characteristics of an organism

Seedling — a young plant

Selective breeding — when humans deliberately breed plants or animals to have specific desirable characteristics

Top-growth — the above-ground parts of a plant

What is orange, supposedly helps you see in the dark, and is one of America's favourite vegetables? The answer, of course, is the humble carrot. The average person eats over 10,000 of these tasty and nutritious vegetables in a lifetime. However, while this colourful vegetable is a staple in many people's diets, carrots can be tricky to grow, owing to their inconsistent germination, slow growth and specific environmental requirements.

In the USDA Vegetable Crop Research Unit, Dr Bill Rolling and Dr Jenyne Loarca are working to improve crop productivity for carrot farmers. Bill is investigating the factors that influence carrot germination, while Jenyne's research focused on the genetics of carrot growth. Together, their discoveries are helping plant breeders to create more successful carrot cultivars.

What influences carrot germination?

Bill is interested in whether the size of a carrot seed influences its performance. Do larger seeds have a higher chance of germinating? Do they produce healthier seedlings? Do the seedlings grow faster? "Carrot germination is complex," explains Bill. "It is influenced by the environment, seed quality and genetics." For example, cold weather can kill carrot seedlings, a lack of moisture can reduce germination, too much water can drown seeds or make seedlings prone to disease, and seeds that have been stored for a long time are less likely to germinate. The unique genetic information contained within each seed determines how well it germinates and grows.

What influences a carrot's phenotype?

A carrot's genotype refers to all its genetic material, while its phenotype refers it its physical properties, such as root length, shape


© fusebulb/shutterstock.com

and colour. Bill is studying the genotypes of over 700 different carrot cultivars by sequencing their DNA. "Though most of the DNA sequences are the same, each cultivar has small DNA differences which result in differences in the phenotype," he explains. Plant breeders identify which carrot cultivars have genotypes that produce desirable phenotypes, such as tasty flavours, high nutritional content, and good germination and growth rates.

A carrot's phenotype is not only affected by its genotype, but also by its environment. For example, planting too many carrots in a small space forces the plants to compete for sunlight and nutrients, preventing them from growing as large as they could, while growing carrots in dense or damp soil can result in diseases that reduce the number of carrots fit for harvest. "Fortunately, carrot farmers are very good at creating an environment where carrots grow well!" says Bill.

How is Bill studying carrot germination?

Before investigating whether seed size influences germination and growth, Bill first wanted to discover whether a carrot's genotype influences seed size. To do this, he grew carrots in a greenhouse, allowing him to control the growing environment. As the carrots were all grown under the same conditions, most variations in phenotype result from the cultivar's genotype rather than the environment.

Once these greenhouse-grown carrot plants had flowered, Bill harvested the seeds and used them for the next stage of his research. By measuring the size of the seeds produced by different cultivars and sequencing their DNA, he can now investigate the relationship between genotype and seed size.

Bill is also using these harvested seeds for germination and growth experiments. To study the relationship between seed size, genotype and germination, he is growing carrot seeds in petri dishes in the lab. "Growing seeds in petri dishes allows us to have a large-scale experiment, because petri dishes don't take up a lot of space, and we can quickly observe the number of seeds that have germinated," Bill explains. He can also meticulously control environmental conditions, such as temperature and moisture within the petri dishes, giving a better estimate of how non-environmental factors, such as seed size and genotype, influence germinate rates.

Bill has also planted some of the seeds outdoors in fields to discover how well they germinate and grow under real-world conditions. This is important because carrot farmers do not grow their carrots in petri dishes, but in fields where environmental conditions are less easy to control. "It's important to test if what you're seeing in the lab under controlled growth environments remains true in the field," Bill explains.

What has Bill discovered?

"We are currently in the process of determining if seed size is a phenotype that is related to genotype, or if the environment the seeds are produced in is the key determining factor," says Bill. The preliminary results from his germination and growth experiments suggest that larger seeds are more likely to germinate and grow into larger seedlings. If he discovers that seed size is controlled by genotype, then selective breeding could be used to grow carrot plants that produce larger seeds, benefiting farmers by providing cultivars that germinate and grow more successfully.

What influences carrot top-growth?

While we, as consumers, are interested in the carrot's root, as this is the part of the plant we eat, Jenyne wanted to understand the relationship between a carrot's genotype and its top-growth characteristics, as it is the above-ground part of the carrot plant that competes with weeds for sunlight. This is especially important for organic farmers, who are not allowed to spray herbicides to remove weeds.

To do this, Jenyne grew 700 different carrot cultivars in a field. Previous studies had compared fewer than 20 carrot varieties, and this was the first study to investigate such an extensive range of carrots.

Jenyne and her team collected measurements of different phenotype characteristics throughout the growing season, such as top-growth height and canopy cover. From these data, Jenyne used statistical techniques to explore the relationships between these characteristics. Then, by combining the phenotype data with genotype data from the different cultivars, they determined that top-growth phenotype variation is due largely to genetics, rather than environmental influence, and they discovered the specific genes that result in specific top-growth characteristics that outperform weeds. Furthermore, Jenyne found that that some of the seed traits that Bill studies affect top-growth phenotypes, with larger seeds producing taller top-growth.

What are the benefits of Bill and Jenyne's research?

Carrots are notorious for their slow and inconsistent germination and growth, which can cause problems for farmers. "Carrot growers have highlighted that improved germination and growth would be helpful to them," says Bill. "We hope to apply our research to carrot breeding programmes, to provide cultivars that perform better early in the growing season with faster and more consistent germination and seedling growth."

"Uncovering the genetic causes of top-growth characteristics was an important finding," says Jenyne. "It means we can select the best-performing carrots to use as breeding parents to create new carrot varieties that have more vigorous top-growth. These new cultivars will especially help organic farmers, as the plants will naturally outcompete weeds without the need for herbicides."

But this research is not just important for carrot farmers. "Carrots are a very nutritious crop," explains Bill. They are a good source of the nutrients that help our bodies make vitamin A, which is needed to keep our eyes and immune system healthy. "To achieve global food security, we must produce enough calories and nutrients for everyone in a sustainable way, while also ensuring farmers can make a living." Bill and Jenyne hope their research will do just that.

About *plant genetics*

It was through plants that scientists first discovered the concept of genetics. Gregor Mendel, a 19th century biologist, grew peas and studied the ways in which offspring inherited characteristics from their parent plants. Mendel's discoveries still form the basis of genetics to this day.

Plant genetics has important real-world applications, particularly in agriculture. Through selective breeding, plant geneticists can create crop varieties that are more suited to our purposes than their wild relatives. For example, broccoli, cauliflower and cabbage are all derived from wild mustard. By selectively breeding for specific characteristics, such as the size of the buds, flowers or leaves, farmers have produced many different vegetables from one species of wild plant.

How can plant genetics address global food security?

"Did you know that of the 320,000 plant species known to science, more than 50% of the human diet is composed of only three species?!" asks Jenyne. While our ancient ancestors ate around 6,000 plant species, today, humans only cultivate 150-200 species, and just nine of these provide more than two thirds of total crop production! Can you guess what these nine key crops are?* "This means there is a lack of biodiversity in global food systems, so agricultural research is key for ensuring global food security," says Jenyne. "As the climate changes, what will happen if these nine key crops become ungrowable?"

Through selective breeding and genetic modification, plant geneticists can improve the yields and nutritional quality of crops. "We are developing crops that are more resistant to pests, disease and drought, crops that are more efficient in their use of water and soil nutrients, and crops that are more nutritious," explains Bill. Plant breeders hope these new crop varieties will continue to feed the world's growing population as climate change causes growing conditions to become less hospitable.

*Answer: rice, wheat, corn/maize, sugar cane, potatoes, soybeans, oil-palm fruit, sugar beet, cassava

Pathway from school to *plant genetics*

- At school, biology will teach you about plants and the basics of genetics. At college or university, courses in plant genetics, plant breeding, horticulture, agricultural studies or biology could all lead to a career in plant genetics.
- Statistics play an important role in plant breeding, as geneticists use statistical techniques to analyse experimental data, so take statistics courses at school and university. "Statistics is best learnt through application," says Bill, "and plant geneticists get lots of chances to practise!"
- "Scientists increasingly need the ability to code," says Jenyne. "If your school or local community college offers a class in programming, try it out! Learning R or Python will give you a big advantage."
- Get growing! Try growing plants on a windowsill, in a school garden or at a local farm.

Explore careers in *plant genetics*

- "Plant breeding is great because you can do something different every day," says Bill, who divides his time between producing seeds in greenhouses, taking phenotype measurements in fields, extracting and analysing DNA in the lab, and writing up results in his office.
- As it is such a diverse field, you can find a role in plant genetics that combines your interests. For example, bioinformaticians use computer coding techniques to analyse large datasets, while engineers design and build the equipment needed for breeding experiments.
- "If you like travelling, consider becoming a plant breeder," Jenyne says. "As the environment plays an important role in plant phenotypes, breeders grow new test varieties around the world to determine which have the best performance in different locations. Breeders travel to each field and take notes on the new varieties."
- "Summer is a busy time for plant researchers in the field and lab, and we need all the help we can get!" says Jenyne. So, reach out to local university agriculture departments and ask if they have part-time work in their plant breeding programmes, or genetics or plant science labs. If you prefer working with plants, look for jobs at local plant nurseries and garden centres. "This experience can help you decide if you are interested in agriculture and plant biology," says Bill.
- The University of Wisconsin-Madison has resources about plant breeding to inspire young people to consider a career in the field: **www.plantbreeding.wisc.edu/educators**
- The Crop Science Society of America has a wealth of resources about careers with crops, including profiles of people working in different fields and tips for getting started: **www.crops.org/careers**

© Mr.Alex M/shutterstock.com

Meet *Bill*

Growing up on a dairy farm, I was surrounded by agricultural experiences from an early age, and I helped care for our cows and produce crops. At school, I enjoyed science classes, especially biology, so I went to university to study biology. I have been fortunate to combine my experiences growing up with my education to research solutions to agricultural problems.

My internship at Arcadia Biosciences, a company focused on using biotechnology to develop novel characteristics in crops, was a great experience. Previously, I had only been involved in traditional plant breeding research, where you cross-breed two cultivars to get specific characteristics of interest. At Arcadia, I assisted with projects applying genetic engineering to target specific DNA sequences to improve the nutritional value, shelf life and drought resistance of wheat, rice and soybean.

I really appreciate the variety of crops that I have had the chance to study. As well as carrots, wheat, rice and soybean, I have also worked with sugar cane and lychee! It is interesting to learn what qualities producers and consumers are looking for in each crop and what each plant contributes nutritionally to our food systems. In the future, I hope to not just complete research but also breed and create my own improved cultivars for farmers and gardeners to grow.

Did you know that the first domesticated carrots were white and purple? Carrot roots can be orange, red, yellow, white or purple, due to different compounds in the plant, and each variety has different health benefits. Orange carrots provide vitamin A, which we need to keep our eyes and immune system healthy. Red and yellow carrots may reduce the risk of certain cancers. As a source of fibre, white carrots are good for digestive health. And purple carrots contain antioxidants.

Meet *Jenyne*

When I was younger, I loved any projects that involved being creative rather than following instructions. I enjoyed inventing new games to play and creating new dishes by changing the ingredients in recipes. I still draw on this creative nature to develop new plant genetics research projects.

After college, I worked at a seed company for three years, where I bred hot peppers and cucumbers. Like Mendel, I used genetic knowledge to cross-breed complementary parents, then evaluated the offspring for the combination of characteristics I wanted them to have, like disease resistance and great fruit quality. This experience made me want to run my own breeding programme!

I am a first-generation American, raised in a multigenerational household with my Guatemalan relatives. My abuela (grandmother) was particularly influential in cultivating my strengths as a scientist. The culture in school was one of perfectionism and 'black and white' thinking, but at home I had the freedom to be creative, experimental, and to think in colour. This way of thinking helps me solve complex real-world science problems, which require non-linear, multi-perspective solutions.

In high school, I found science boring as it was all about memorising facts. If, like me, you aren't thriving in an education system built around test-taking, keep going – be curious anyway, do your best, and surround yourself with people who remind you of your strengths. Your commitment, passion and eagerness to learn will take you far. And remember – your grades do not reflect your potential or your personal worth!

I used to struggle with math, and it was not until I was in college that I was diagnosed with dyscalculia (a learning disorder like dyslexia, but for math, that is underdiagnosed in young girls). This diagnosis taught me that I was not 'bad' at math, or 'lazy', but that the part of the brain involved in learning math operates differently in me than in neurotypical people. I considered dropping out of my PhD because I worried about how much math is involved in research, but with patience, persistence, practice and self-belief, I focused on my strengths and became good at the statistical skills I need to succeed in my career. Remember – having a learning disorder does not mean that you are not smart or capable. If you suspect you might have one, try to get tested and find support to help you use your unique strengths.

I want to raise the profile of Latinx (people of Latin American cultural or ethnic identity) in STEM. Prejudice and discrimination mean that we have historically been excluded from science, and, especially in agriculture, there is a lack of representation of Latinx people in leadership positions. Advancing agriculture through studying plant genetic resources is one way to have a positive impact on agrobiodiversity.

Supporting small farms: how protecting local farms can protect local communities

Small farms make up more than half of the agricultural land in the US and produce just over a fifth of the country's agricultural produce. Not only do they play a vital role in feeding people, small farms are also integral to local communities. And yet, many small farmers have limited access to resources and find themselves at a social disadvantage due to bias and prejudice. **E'licia Chaverest**, from the **Small Farms Research Center** at **Alabama A&M University**, USA, is supporting these farmers to help them run successful and resilient farms.

E'licia L. Chaverest

Assistant Director, Small Farms Research Center, College of Agricultural, Life and Natural Sciences, Alabama A&M University, USA

Field of research
Small Farms

Research project
Supporting limited resource, socially disadvantaged farmers in Alabama to manage successful and resilient farms

Funders
US Department of Agriculture National Institute of Food and Agriculture (USDA-NIFA), USDA Risk Management Agency, Southern Extension Risk Management Center, Southern Sustainable Agriculture Research and Education (SARE), USDA Office of Partnerships and Public Engagement-2501 Project

This work is supported by the US Department of Agriculture (USDA), under award numbers USDA-NIFA FSOP 2020-70020-32265, USDA-BFRP Federal award 2021 - 49500-35644, USDA-RMA 15570, and University of Arkansas-Southern Risk Management Education Center 14869. The contents are solely the responsibility of the authors and do not necessarily represent the official views of the Alabama A&M University, USDA or the University of Arkansas-Southern Risk Management Education Center.

PROFILE

Talk like a ...

small farms outreach provider

Attorney — a person, typically a lawyer, appointed to act for another in business or legal matters

Experimental learning — the process of learning by doing. Hands-on experience can make it easier for students to learn and retain information

Limited resource farmer — a farmer who has limited or no access to the resources needed for managing a successful farm, such as specialised machinery, high quality seed, financial support or financial literacy

Monocrop — cultivation of a single crop species

Small farm — a farm (often family-owned) with an income under US$250,000 per year

Small farmer — someone who owns or manages a small farm

Socially disadvantaged farmer — a farmer who experiences prejudice, bias or discrimination due to their gender, race, ethnicity or nationality, which adds to the challenges of farming

What did you have for dinner last night? Whether it was steak and chips, a chickpea curry, or beans on toast, the chances are that most, if not all, of the ingredients were grown or reared on a farm. It can be easy to forget this. Go into any major supermarket and you will be confronted with aisle after aisle of plastic packaging and brightly coloured branding. Despite appearances, the vast majority of the food in our supermarkets started out in the dirt.

Since the advent of agriculture, roughly 12,000 years ago, we humans have relied on farming for our very survival. Even today, with our Big Macs, Whoppers and vegan chicken nuggets, farmers are the people who put food on our tables.

Some farms can roll on for thousands and thousands of acres. Huge fields of monocrops, like corn and wheat, stretch out beyond the horizon and gigantic barns stuffed full of cows, pigs and chickens see millions of animals slaughtered every day. But not all farms are like this. In fact, 89% of farms in the US are classed as small farms.

These small-scale farms are vitally important, particularly for local communities. Small farms can support local businesses, create jobs for local people and bolster the local economy. During the COVID-19 pandemic, for example, global food supply chains collapsed, and many local farms stepped up to provide their local communities with food. Small farms are also much kinder to their local environments; biodiversity is much higher around them than around large, industrial-scale farms.

Unfortunately, running a small-scale farm is not easy. Smaller farms tend to have smaller financial margins, so one bad harvest, a sudden change in market conditions, or an extreme weather event can be disastrous. As the effects of the climate crisis start to kick in, farms of all sizes are struggling to adapt to changes in weather patterns and soil conditions. With less access to technology and fertiliser, small farms are particularly vulnerable to the effects of climate change.

Eddie and Ruby Smith, veteran farmers located in Greensboro, Alabama. © Dr Duncan M. Chembezi

Managing a successful small-scale farm is demanding work, even at the best of times. It is particularly difficult for those farmers who are socially disadvantaged or who lack access to resources. Unfortunately, farmers from minority backgrounds may receive less support from government services and programmes, and they may find it harder to acquire the resources needed to to manage a successful farm.

E'licia Chaverest is the assistant director of the Alabama A&M University Small Farms Research Center (SFRC). She, along with others at the SFRC, is dedicated to helping limited resource, socially disadvantaged farmers in Alabama to manage profitable and resilient farms that benefit their local communities.

How does the SFRC help?

"The SFRC is actively involved in developing policies and programmes that aim to assist socially disadvantaged, limited resource minority farmers," says E'licia. For example, E'licia has served on the New and Beginning Farmer Advisory Committee as part of a programme offered by the US Department of Agriculture (USDA). Her colleague, SFRC AAMU Director Dr Duncan M. Chembezi, inspired E'licia to apply for the position. He also recently held lengthy terms on the Advisory Committee on Minority Farmers, another important USDA programme. The SFRC will always have a seat at the table when policies and programmes are being developed. "We are here to be a voice for the voiceless," says E'licia.

The New and Beginning Farmer Advisory Committee is responsible for developing a programme of support, and advises on loan requirements for new farmers who do not have much experience and need a helping hand to get started. By serving on this committee, E'licia can provide a voice for socially disadvantaged farmers and figure out how the programme can be changed to better support them.

The SFRC conducts research into the issues that affect limited resource farms and how these issues might be overcome. It also helps socially disadvantaged farmers to implement environmentally friendly practices on their farms and successfully market their produce, ensuring that these farms are both environmentally and financially sustainable.

The SFRC recognises that one of the main challenges for socially disadvantaged farmers is their lack of access to government funding and services. Often, this is because of structural racial discrimination or bias, which makes it harder for certain people to access these support systems. The SFRC works closely with government agencies and farmers to mitigate these challenges.

Therefore, one of the SFRC's priorities is to help socially disadvantaged farmers access key support so that they can address their farm endeavours. The SFRC helps farmers write grant proposals, facilitates one-on-one consultations with representatives from the USDA, develops educational programmes, such as conferences, seminars and workshops, at which farmers can find out about government initiatives. In addition, the SFRC provides training on new and emerging issues that directly affect farmers in general.

What happens at an SFRC conference?

The SFRC conferences are attended by small farmers from across that state of Alabama and beyond, local representatives from the USDA, charitable organisations and credit unions, which can grant loans to farmers. The conferences feature presentations from extension agents, agricultural organisations, researchers, government representatives and successful small farmers.

These gatherings allow socially disadvantaged farmers to access information and engage with other people in their industry. The SFRC hopes that these conferences and workshops will foster a sense of community between local farmers that encourages them to share advice and support each other. Indeed, the SFRC also encourages small farmers to forge relationships with USDA agencies prior to needing their services.

In addition, the conferences give farmers the opportunity to take part in training and workshops that are designed to help them make their operation more sustainable and marketable, as well as to provide information on which services are available to them and how to access them. "This allows farmers to learn fully about government programmes in a non-judgemental environment," says E'licia.

What kind of government programmes are available?

One of the most recent USDA programmes that the SFRC is implementing focuses on providing food safety training for socially disadvantaged farmers. This programme uses experimental learning to help teach the farmers new food safety practices to apply to their farm operation. "Experimental learning is the process of doing something to understand it," explains E'licia. "Participants engage with a task and then reflect on it to understand how it can be applied to their farm. Basically, we are taking the classroom to the field." This project will include hands-on food safety demonstrations, computer literacy training and local farm visits.

How successful has the SFRC been in helping socially disadvantaged farmers?

The SFRC is constantly being recognised by the USDA for the work that it does. "This makes me proud because our team is constantly making an impact in the agricultural community by educating and empowering farmers," says E'licia. "The USDA recognises our impact, effort and commitment to the farmers of Alabama."

In 2020, one of E'licia's projects that focused on financial literacy training for socially disadvantaged farmers received an award for its excellence. "This made me realise that I was truly making a difference in my community," says E'licia.

Despite the amazing work of the SFRC, limited resource, socially disadvantaged farmers still face many challenges. The SFRC remains committed to helping farmers navigate these challenges so that they can find stability and continue to support their local communities.

About *small farms outreach*

Small farms outreach focuses on finding new and innovative ways to support small, local, family-run farms. This can include developing new sustainable practices, designing and delivering training programmes or creating spaces for small farmers to share information and collaborate with each other.

Small farms have an important role to play in local communities. They strengthen the local economy, provide jobs to local people, and can even help to support local wildlife. Small farms can help local people feel connected the land around them. For communities with small farms, it can be easier to see the direct link between how we treat nature and how nature treats us in return.

Local farmers can act as role models to young people in a community. They give back to the community by volunteering, donating food and employing local people. They can also help to educate young people about their relationship with nature and influence the next generation of young farmers. Local farmers can teach children how to grow their own fruit and veg and show them that almost all the food that they eat comes from the natural world.

What does the future of small farms outreach look like?

"In the near future," says E'licia, "we will need environmental scientists to find ways to combat climate change with less resources and more sustainable techniques." The effects of climate change are already disrupting farming practices all over the world. Droughts, flooding, extreme temperatures and soil erosion are just some of the things that will make life difficult for small farmers.

One of the most pressing issues currently facing socially disadvantaged farmers is a lack of access to legal advice and support. Many minority farmers are losing their land because they do not have proper plans in place to ensure that their farms are passed on to their next of kin. Helping socially disadvantaged farmers to access legal advice and work with attorneys will be an important part of small farms research over the coming years.

Pathway from school to *small farms outreach*

- Studying science subjects at school is important. Many topics within biology, chemistry and geography could come in handy, including ecology, plant biochemistry and soil science.
- Many other subjects could also be useful. For example, English could be useful when helping farmers complete funding applications. Maths and economics could be useful when helping farmers with their finances, and law could be useful when helping farmers navigate legal issues that they might face.
- The SFRC employs people who major in agriculture, animal science, biology, microbiology, soil science, agricultural economics and other related fields.
- The SFRC offers internships and mentorships for students. See if any colleges or universities in your local area offer these kinds of opportunities within the field of agriculture.
- The College of Agricultural, Life and Natural Sciences at Alabama A&M University (**www.aamu.edu/academics/colleges/agricultural-life-natural-sciences**) offers a wide range of subjects that will enable students to assist farmers.
- Check out your local area extension office for the 4-H programme. For example, Alabama 4-H seeks to empower youth with the skills to lead our communities, our state, our nation, and also our world. Alabama 4-H is open to all youth aged 9-18 and exists in all 67 Alabama counties. It is the largest youth development programme in Alabama: **www.aces.edu/blog/topics/about-4-h/about-alabama-4-h**
- At high school, E'licia was President of Future Farmers of America (FFA). "There are many opportunities within this organisation," she says. FFA is an intra-curricular student organisation for those interested in agriculture and leadership: **www.ffa.org/about-us/what-is-ffa**
- MANRRS empowers future leaders in agriculture, natural resources and related sciences, and has a programme for students in grades 7-12: **www.manrrs.org/junior-manrrs-benefits**

Explore careers in *small farms outreach*

- Agricultural science societies are great places to find information on new developments in the farming industry, particularly around sustainability. For example, the Agri-Science Society (**agssbd.org**) focuses on improving farming practices via digitisation, the Agricultural Science Association (**asaireland.ie**) has a great podcast that features farming experts, and the Small Farms Association (**small-farms-association.co.uk**) offers practical advice for new small farmers.
- Farm shows and agricultural seminars and conferences are common in many parts of the world. Find one in your local area and talk to the people that you meet there. One of the best ways to learn about farming is to talk to farmers!

Honey bee farmer Marguerite McClintock, owner of Alchemy Farms and Plants LLC, teaching youth about honey

Q&A

Meet *E'licia*

What influenced you to study agribusiness management?

In 1996, as an incoming first-year student, I took part in the Alabama A&M University USDA Summer Assistantship programme. I thoroughly enjoyed this programme and was open to the many opportunities in the area. This led to me studying for bachelor's and master's degrees in agribusiness management.

What do you love most about what you do?

I love working with the farmers. All the farmers have a rich history and a story about their life to share. I have learned about the history of Alabama and farmers' rights, and love to educate and empower them in their livelihoods.. They have taught me to enjoy life and laugh as much as I can.

> ***If you don't go after what you want, you'll never have it. If you don't ask, the answer is always no. If you don't step forward, you're always in the same place.***
>
> ***Nora Robert***

What skills help you succeed in your role as assistant director of the SFRC?

I have a lot of tasks to complete, but delegation helps. However, I think the most important skills are to learn to work with people, read people and treat people well. These skills are underestimated yet so important.

How do you manage aspects of your role that you're not so good at?

Honestly, I take classes and I am not ashamed to ask questions and assistance.

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

The worst piece of advice given was the cliché 'fake it until you make it'. This is the worst advice, because if you're not careful, it will stunt your personal and professional growth, and slowly diminish your character.

In addition, you will find yourself not willing to put in the work, time and effort to learn new things because you are fearful about what someone might think of you. It reminds me of the literary folktale written by Danish author Hans Christian Andersen, *The Emperor's New Clothes.* The storyline highlights a vain emperor who gets exposed in front of their peers. By constantly pretending instead of learning, you find you are only deceiving yourself by avoiding the learning curve and everyone knows who you really are except for you.

I recognised that the learning curve is the perfect time to ask questions and look silly, so to speak, until you learn more and find your direction. I unlearned this cliché by developing excellent work ethics, by cultivating meaningful partnerships on a subject matter, by constantly asking questions, and by being okay with feeling uncomfortable in order to improve. I recognised that everyone must go through the learning curve to grow, inspire and become.

What is your philosophy in life that has helped drive you forward?

I do have a mantra about life. This mantra written by Nora Robert has been a gift that keeps on giving, especially when I read and apply it: "If you don't go after what you want, you'll never have it. If you don't ask, the answer is always no. If you don't step forward, you're always in the same place."

E'licia's *top tips*

1. You never know what opportunities will come your way. Be open to learning new things throughout your whole career.
2. Grow your own food, if and when possible. Visit farmer's markets and talk to farmers. See what it's really all about.
3. Never stop being curious. You will be surprised how the world of agriculture can change how you see food.

Urban farming for urban families

Our well-being is intimately linked to the food that we eat and the places where it is grown. Healthy soils produce nutrient-dense food, which helps us stay healthy, both in body and in mind. For those of us who live in cities, it can be difficult to find fresh, good quality, local food. At **15th Street Farm** in Florida, USA, **Emmanuel Roux** and **Professor David Himmelgreen** run an education project to help local families learn about their local food systems and make healthier food choices.

Emmanuel Roux

Director and Program Developer,
15th Street Farm, St. Petersburg, Florida, USA

Fields of research
Urban Farming, Farming and Nutrition Education, Agritourism

Professor David Himmelgreen

Department of Anthropology and Director at the Center for the Advancement of Food Security and Healthy Communities, University of South Florida, USA

Fields of research
Anthropology, Nutritional Anthropology

Research project
The 15th Street Farm nutrition education program (NEP)

Funder
US Department of Agriculture (USDA)

PROFILES

Talk like a ...

farming and nutrition educator

Anthropology — the comparative and global study of humans, their biology, culture, material-remains and language in the past, present and future

Decomposition — the process of organic matter being broken down into simpler molecules, such as carbon dioxide, water, nutrients and nitrogen

Food security — having access to enough safe, nutritious and socially acceptable food for normal growth and development and an active, healthy life

Microorganism — any organism that can only be seen through a microscope such as bacteria, fungi and viruses

Nutrient cycling — the system that transfers energy and matter between the living and non-living parts of an environment

Urban farm — a green space within a city that is used to grow food and other crops and educate the public on the natural world

Have you ever stood barefoot in the mud and felt it squish and squelch between your toes; scrabbled around in the dirt and hunted for beetles, worms and slugs; or scooped up a handful of soil and let it fall through your fingers back to the ground?

The next time you are cleaning dirt out from underneath your fingernails, take a moment to consider the fact that one gram of healthy soil can contain up to 1 billion microorganisms. Incredibly, there are more microorganisms in one tablespoon of soil than there are human beings on the planet.

The soil in our fields is a bustling metropolis inhabited by bacteria, fungi and all sorts of other microorganisms. These microorganisms interact with each other in a complex network of relationships that underly many important processes, such as decomposition and nutrient cycling. As in a city, where people collaborate to keep society functioning, each organism in these communities has its own role to play to ensure that the soil stays healthy. The health of soil has a direct impact on the health of the plants and animals that live within it. For example, crop plants that grow in healthy soil are much more likely to be immune to diseases and able to flourish and produce plentiful, nutrient-rich harvests.

It is estimated that soils are responsible for producing 95% of the food that we eat, either directly, through growing crop plants, or indirectly, through growing plants that are fed to the animals that we eat. In this way, the health of soil determines the quality of the food that we eat, which in turn has a huge impact on our health and well-being; 'we are what we eat'.

The connection between farming, nutrition and well-being can be seen on urban farms. These small-scale farms are found in cities all over the world and are important cultural resources. People living in cities can visit urban farms to learn about farming, purchase healthy, local food, and reconnect with the natural world that they are so often cut off from.

15th Street Farm in Florida is home to a nutrition education program (NEP) designed to reduce food insecurity in the local area by teaching local children and their families about their local food systems. The 15th Street Farm NEP is run by Emmanuel Roux, Director of 15th Street Farm, and Professor David Himmelgreen, Department of Anthropology and Director of the Center for the Advancement of Food Security and Healthy Communities at the University of South Florida. Emmanuel is a chef, restauranteur and urban farmer, and David is a professor of anthropology. Combined, their expertise brings people and communities together through an appreciation of nutritious food, farming and the natural world.

Who is the 15th Street Farm NEP designed for?

"The 15th Street Farm NEP is serving school-aged children and families who primarily live in marginalised communities," explains David. Additionally, teachers from schools in the local area are being provided with tools, facilities and training to promote healthy food choices. "The goal," continues David, "is to transfer knowledge and skills to reduce food insecurity and increase community involvement in developing local and regional food systems."

What do students learn?

The 15th Street Farm NEP teaches its students about the links between agriculture, nutrition and wellness. "Soil and plant health are interconnected with human health and well-being," says David. "This is critically important in light of modernisation and the disconnect between humans and the natural world."

"We try to show our students that humans are very much a part of nature and not separate from it," says Emmanuel. "Food does not come from the supermarket. Somebody has to prepare the soil, sow the seeds, grow the plants, harvest the produce and then distribute the food for us to enjoy."

The NEP involves installing school gardens to enable children to see the connection between the natural world and the plants that provide us with food. This hands-on approach helps students develop an emotional attachment to food they have grown and to discover the taste of fresh, nutrient-dense vegetables. "We focus on 'Good Food', which we define as tasty, healthy, good for the body, and good for the environment," says Emmanuel.

How does the 15th Street Farm NEP teach its students?

Emmanuel and David have developed novel educational approaches using simple metaphorical concepts (such as the soil as a city) and providing teachers with the teaching tools needed to apply learning in the garden to a variety of curriculum subjects. The outdoor learning results in greater student engagement and impacts human and environmental wellness.

For example, one activity asks students to look at an old tree and imagine its history. Students consider questions such as 'how was it born?', 'what challenges did it overcome in its life to enable it to grow?', 'how has the environment changed during its lifetime?' and 'what interactions might it have had with animals and humans?'. These questions are designed to help students build an appreciation and reverence for the plants they see around them and to imagine the world from the plants' point of view.

Another activity aims to expand students' taste buds by encouraging them to grow, harvest, eat and share unfamiliar plants. "We grow unusual plants that offer a very contrasted range of tastes, from French sorrel to dandelion, from nasturtiums to strawberries and papayas," explains Emmanuel.

"We have developed an age-appropriate, hands-on curriculum to stimulate children's curiosity and passion for gardening, nurturing plants, and eating food that looks beautiful, tastes good and is beneficial for their health and the environment's well-being," says David.

What challenges has the NEP faced?

Emmanuel and David wanted to interact with children and young people from a variety of age groups. This made it difficult to design a curriculum and appropriate activities for all ages. To overcome this, they made the NEP dynamic and flexible so that it could be adapted depending on the age and interests of the students taking part.

Another challenge was getting the support and buy-in from local teachers. Teachers in the area are already overworked and often receive little praise or appreciation for their work. Emmanuel and David have worked hard to ensure that teachers taking part in the NEP are provided with the support they need, in the form of information and school garden maintenance.

What are the next steps for the 15th Street Farm NEP?

"We are currently writing a progress report on the first year of the NEP for the USDA," says David. "In the NEP's second year, we plan on increasing the number of schools participating in the programme." David and Emmanuel will also conduct a photo-voice project in which students will take photos of their time at 15th Street Farm and the school gardens. These photos will form an exhibition, highlighting the benefits the NEP has on families in the local community.

Emmanuel and David plan to look for grant opportunities to help fund the project beyond 2024, to continue working with the local community. David and Emmanuel hope that the impacts of the NEP will live on for years to come.

About *anthropology*

Anthropology is the study of human biology, behaviour, cultures, societies and languages. Some anthropologists focus their studies on the past, looking at the origins of human cultures and how they have developed since the evolution of our species. Other anthropologists focus on cultures that exist today, often helping them to tackle the challenges they face.

Meet *David*

I majored in anthropology and biology at university. I took courses with a biological anthropologist who inspired me to study how humans use biology and culture to adapt (or not) to stressful environments such as food scarcity, extreme temperatures, and common diseases. During graduate school, I did field work in rural India and Lesotho among marginalised communities experiencing nutritional stress.

In the early 1990s, I was doing my doctoral research in Lesotho, Southern Africa. This was when South Africa was transitioning from the Apartheid system (based on racial segregation and run by an all-white government) to a democratic republic. It was both an exciting and challenging time to be in this part of the world.

More recently, I have been working with Feeding Tampa Bay and other local agencies to address food insecurity. In 2020, I founded the USF Center for the Advancement of Food Security and Healthy Communities which conducts research and programme evaluations, provides education on the long-term effects of food insecurity on health and well-being, and trains students to become the next generation of leaders addressing food insecurity.

Food is central to the human experience. People don't just produce and eat food to survive, they also attribute meaning and values to food. Food brings people together but can also divide them. Food insecurity is a longstanding global problem that is tied to political, economic and social inequalities and inequities.

Projects like 15th Street Farm NEP can help towards tackling food security by providing knowledge, skills and agency to young people so that they will have a role in developing a food system where nutritionally adequate, safe and socially acceptable food is available and accessible.

I am proud to be training a new generation of students who are laser-focused on social justice.

Recently, I was elected as a Fellow of the American Association for the Advancement of Science for my "distinguished contributions to the field of anthropology, particularly for research and programmes mitigating global food insecurity, especially for marginalised populations, in relation to HIV/AIDS and nutritionally related diseases".

Pathway from school to *anthropology*

- A liberal arts education is essential for developing critical thinking and global citizenship, both of which will help you in your career as an anthropologist. The liberal arts consist of the natural sciences, like biology, ecology and neuroscience, formal sciences, like physics and maths, social sciences, and the humanities.
- Other skills that will help you become a successful anthropologist include research, writing and public speaking skills.
- Contact local universities or colleges to see whether they have any internship, work experience, or summer school opportunities in their anthropology departments. This is a great way to get practical experience and to assess whether anthropology is right for you.
- There are lots of anthropology volunteering programmes which allow you to travel abroad and support communities all around the world whilst simultaneously learning about anthropology.

Explore careers in *anthropology*

- Websites such as the American Anthropological Association (**www.americananthro.org**), the Society for Applied Anthropology (**www.appliedanthro.org**), and the Royal Anthropological Institute (**www.therai.org.uk**) are all great places to learn more about the field of anthropology.
- Anthropologists can use their expertise in a variety of areas, including academia and research, business and marketing, the charity sector, and even in government.
- Anthropologists can use their knowledge and expertise to help communities all over the world tackle their own unique challenges. An understanding of different customs, cultures and traditions allows anthropologists to engage with all sorts of different communities.

David's *top tip*

Be passionate and persistent in reaching your goals.

About *agriculture*

Agriculture is the process of nurturing soil and microorganisms, planting and harvesting crops, and raising livestock. The agricultural revolution took place over 10,000 years ago and was a major step in the development of human culture and civilisation. Since then, humans have been reliant on farming for almost all our food. Chemical farming has damaged the environment, including soil. New organic methods aligned with natural systems are being implemented and will reduce the negative impacts of chemical overuse.

As weather patterns continue to be affected by climate change, farmers all over the world are having to adapt their practices to produce enough food. Farmers are benefitting from a greater understanding of soil microbiology and new technologies to make their farms more efficient. Some are turning to regenerative agriculture techniques and practices such as agroforestry (growing crops or raising livestock in forests).

International conflicts, like the war in Ukraine, and disruptions to global supply chains, like those caused by the COVID-19 pandemic, have made global food distribution more difficult. Agricultural science can help farmers improve their practices and produce larger amounts of high quality, nutritional food, relieving some of the pressure on supply chains and protecting global food security.

Meet *Emmanuel*

Growing up on a farm created a connection with the natural world and an intimate understanding of agricultural crop production, transformation and cooking – and the sharing of the end result.

Running your own restaurant is very demanding and always unpredictable, requiring diplomacy and creativity. However, the rewards are the immediacy of customers' feedback and the pleasure of creating and serving good food.

I was influenced by my uncle, Dr Jacques Bas, a French gastroenterologist (someone who studies the digestive system). He was a very early pioneer and discoverer of the importance of gut and soil microbiomes and a pioneer of organic agriculture in the mid-20th century in France.

I am passionate about urban agriculture because food and urban food production is a strong community binder.

I am proud of being able to share knowledge about natural systems, to illustrate the connection between soil microbiome health and human wellness, and I love great dinner parties!

Pathway from school to *agriculture*

- Subjects like biology, chemistry, botany, environmental science and geography will set you up well to study agricultural science at college or university.
- Contact your local university and see if they offer agricultural science courses and any internship or work experience opportunities.
- Urban farms exist in cities all over the world. Take a visit to your local city farm and ask about any opportunities you could get involved with. It may have a volunteering programme you could take part in. If your school does not have one, propose to start and maintain one!

Explore careers in *agriculture*

- A career in agriculture does not necessarily mean being a farmer. With an agricultural science degree, you could become a soil scientist, plant breeder, agricultural consultant or forest and woodland manager.
- Emmanuel's background is as a chef and restauranteur. His passion for growing, creating and enjoying food has shaped his career. An appreciation of food and farming could lead to many different career paths, including urban farming, hospitality and teaching.
- The Food and Agriculture Organisation website has lots of information for young people about regenerative farming, soil biodiversity and nutrition. For example, here is a collection of short stories about soil biodiversity: **www.fao.org/documents/card/en/c/cb4185en**
- If you have access to a garden or an allotment, grow your own food and share it with friends and family. There is a huge range of videos on YouTube that can help you get started. Take a look at GrowVeg: **www.youtube.com/@GrowVeg** Get started, put seeds in the ground, water and nurture them, they will grow.

Emmanuel's *top tips*

- Read books, wander and wonder in nature, get your hands in good soil with friends, nurture and grow life. It is grounding and a great antidote to excessive consumerism.
- Cultivate curiosity and share your knowledge. It is very satisfying.
- We are born into a house full of windows and doors to be opened to discover what is outside.

The 15th Street Farm nutrition education programme (NEP) involves a range of people including anthropology students, educational instructors and teachers who all work alongside David and Emmanuel to inspire the young people and families who visit and learn at the farm.

Q&A

Meet *Marcela*

Marcela Munoz Marin
Undergraduate student, Department of Anthropology, Colleges of Arts and Sciences, University of South Florida

Who or what inspired you to pursue anthropology?
With a background in psychology, I am interested in culture and how the human experience is shaped by the connection between individuals and culture.

What is your role on the 15th Street Farm NEP?
My role has been to contribute to organising the information and knowledge from Emmanuel, the programme's director, and the instructors into the programme's curriculum. Next semester, I will be going to the schools and participating in the evaluation of the programme and the curriculum.

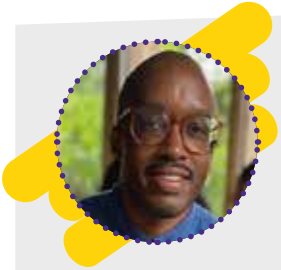
Why is it important for children to be immersed in nature and the environment?
Children are growing up in concrete and with computers, away from nature. This experience is a way for them to learn to enjoy natural environments. Taking care of plants enables them to interact with the environment and their peers, experience a different routine and understand how to take care of themselves and others.

What impact have you seen the 15th Street Farm NEP have on children?
Children learn to enjoy being outside in the sun with nature, and they feel proud of their gardens and their plants. They discover different vegetables, fruits and flavours they are not used to having in their diets. They also gain an awareness of the relationship between health, nutrition and wellness.

What have been the highlights for you of your work on the 15th Street Farm NEP?
My favourite experiences and successes from this programme have been putting together the curriculum to make it accessible and comprehensible for children of all ages. Also, being able to see all the satisfaction the children get from being successful with their seedlings and trying new vegetables is very rewarding.

What are your proudest career achievements so far?
Being able to help people to become their better selves through education.

What are your ambitions for the future?
To follow my passion for education and facilitate the path of students and people to learn, grow and have fulfilling outcomes in their life.



Q&A

Meet *Damien*

Damien White
Instructor, 15th Street Farm, St. Petersburg, Florida

How has your career path led you to the 15th Street Farm NEP?
Prior to moving from Boston to Florida in 2018, I worked in hospital pharmacy. I was ready for a career change and while exploring this, started a home garden. I learnt about growing my own food in Florida. What started as a hobby soon transitioned to a passion, which opened up an opportunity to work in a school garden. Now, my role on the NEP is as an instructor at several schools in the area.

What makes the NEP such an innovative learning programme?
The focus on regenerative farming, specifically the soil. Healthy soil is needed to grow healthy food!

What types of activities do you lead students through?
Garden tastings, growing fruits and vegetables, learning to read nutritional labels and always working on ways to improve the soil.

How do you see the children responding to the programmes you run at 15th Street Farm?
The smiles on the children's faces as they run from the school into the garden that they themselves have been tending to for months says everything. Students love the opportunity to learn outside the classroom. Many students know about gardening science and are proud to show what they already know, especially when they get to apply it to a real-life situation in the garden.

What have been the key successes of the 15th Street Farm NEP, so far?
Kids at one school grow produce and some is given to a local food pantry, providing fresh food to local residents. Another achievement is when students ask for seeds and then later tell me they've started growing vegetables at home. That always puts a smile on my face.

What are the next steps for the programme?
We need irrigation due to dry spells that can last weeks and even months. Unfortunately, irrigation can be quite costly so we would like to drill a shallow well at each school we work with. Shallow wells would allow us to water the crops without paying to use city water.

Meet *Funmi*

Funmi Odumosu
Master's student, Department of Anthropology, Colleges of Arts and Sciences, University of South Florida

I was a STEM major and had dreamt of becoming a physical therapist, but after graduation and working in healthcare for two years, I realised that our current healthcare system does not prioritise the full story of health inequity. I witnessed the power dynamics between insurance companies, providers and patients, as well as the consequences to patient health when policy implementation fails to consider people's lives and experiences. I began to understand that these critical and unheard truths would not be recognised in healthcare without a holistic medical anthropological approach and decided to examine public health inequities from an anthropological lens.

I am project coordinator and evaluator on the 15th Street Farm NEP. I liaise between our community schools, local garden educators, and the university research team. Through curriculums lesson plans on topics such as seeds, insects, soil and biodiversity, I collect data via pre and post surveys of what the children have learnt. This helps me measure the overall success of the programme and consider ways we can improve teaching children the connections between soil, plant and human health.

Teaching the importance of healthy food, where it comes from and how to grow it stems from an appreciation of nature and the environment. When children are immersed in nature, an interconnected awareness is created that allows them to understand and care for living beings around them – from other human beings to the critters and plants of Earth.

The garden is a tremendous place of growth and learning for the children. The school garden requires teamwork, which the students display each time they step into it. They work together enthusiastically, planting and tending to the food of the garden, and are instilled with a sense of self-accomplishment when they finally harvest the food from the seeds they've sown. The garden is also a haven and healing space for them where they can wind down, connect with nature and experience learning outside of traditional classroom structures.

A key success for me was getting the children to try new foods! We see children go from being hesitant, to being curious and excited to try something new and expand their taste horizons. These are great moments for the children and the teachers.

My proudest career achievements have been being able to publish meaningful work that speaks to the truths of how health is impacted by structural power and systemic inequities. Bringing these truths to light, not only in academic formats but also in more accessible formats for the general population, creates conversations around solutions to health disparities and brings us closer to change.

I aim to engage both academia and the broader community in the fight for food sovereignty and health equity. After graduating from my current master's programme, I aspire to get a master's in public health and use a holistic approach to demonstrate how structural inequities pervade every aspect of health and well-being, including access to healthy foods. I hope to continue to do community-based work, around school gardens and the school curriculum.

Funmi's *top tip*

To engage in food justice work, it's important to work closely with and listen to the stories and truths of the residents of the community. They live there, they know what they need, what has worked and what won't work. One of the most important things to remember as a community-based researcher is that everyone has their own experience and knowledge; our job is to give them a voice.

© Rawpixel.com/shutterstock.com

Futurum Careers is five years old!

In September 2018, co-founders **Brett Langenberg** and **Karen Lindsay** published the first Futurum magazine: *Social Mobility and the Sciences*. That issue marked the launch of **Futurum Careers** and, five years on, this is our 22nd. Join us as we look back over the years and celebrate the milestones that have contributed to Futurum's ongoing success.

2018

Global reach

We have published over **420** sets of education resources and **22** issues of the Futurum magazine.

Our educational resources are being used by teachers all over the world. Since we started recording resource downloads in 2019, our handouts have been downloaded **28,205** times from the Futurum Careers website, **30,343** from TES and **29,198** times from Teachers Pay Teachers. That's a total of **87,746** downloads!

Our resources are also freely available on Scientix, a European Commission-funded initiative that supports collaboration among STEM teachers, education researchers and policymakers, the European Geosciences Union and LabXchange, a global science classroom created at Harvard University and supported by the Amgen Foundation.

Differentiated learning

As part of our commitment to widen our reach and support differentiated learning, we started producing:

2019 **PowerPoints,** which focus on career insights and include reflective talking points.

2020 **Animations,** which bring the research stories to life.

2022 **Podcasts,** which feature researchers talking candidly about their personal experiences.

The three most downloaded articles on Teachers Pay Teachers are:

3

Living with drought, floods and climate change

Microplastic pollution: how bad is it and what can we do to solve it?

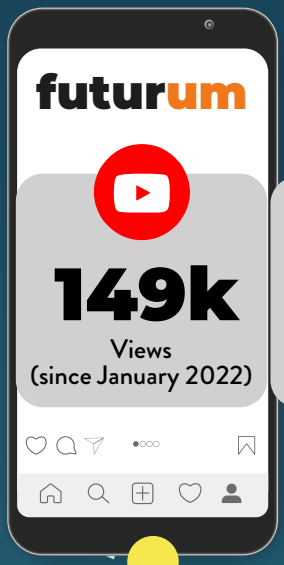
The marine ecosystem: from zooplankton to humans

We have had...

93 teacher reviews

90 of which have been rated 4 or 5 stars.

Digital footprint



149k
Views
(since January 2022)

1.8k
Followers

75k
Average views per month

1.6k
Followers

6.3k
Followers

Parlez-vous français?

We have published 72 sets of translated resources, in languages including French, Spanish, Portuguese, Zulu, Swahili, Bengali, Arabic and Mandarin, allowing our educational resources to be accessed by students around the world and to be used as resources for teaching foreign languages.

Award-winning resources

In 2021, Futurum Careers was named an Innovating Careers Champion by the UK Government's Careers & Enterprise Company (CEC) and listed in its resource directory.

In 2022, Scientix and STEM School Label invited teachers across Europe to vote for the most useful resources in the Scientix repository. Two were from Futurum Careers:

- Using AI and computer science as a force for social good
- The ocean's storage system: how plankton influences climate change

In September 2023, we have been shortlisted for an Open Education Significant Impact Award, which recognises open teaching and learning resources that have significantly impacted accessibility, learning and social change.

2023

Looking forward

Futurum Careers is committed to sharing knowledge, communicating research stories and playing our part in STEM and SHAPE communities around the world. In the near future, we will be talking to bioscience students at the University of Bath, UK, about science communication.

What will the next five years bring? We look forward to continuing to produce high-quality resources that help researchers to inspire the next generation, teachers to deliver a broadened curriculum, and students to aspire to fulfilling and rewarding careers. We will report back in 2028!

Events and talks

We took part in:

Bath Taps into Science Festival, an award-winning family science fair located in Bath, UK.

SparkED Organization's annual conference, which aims to equip youth with the skills and resources they need to make informed career decisions.

International Centre for STEM Education (ICSE)'s #togetherforscience campaign, the aim of which was to show that we are stronger together and that science and cooperation matter.

A webinar at Cheyney University, in Pennsylvania, USA, introducing students to 'The importance of writing in STEM'.

The 2023 European Science Education Research Association (ESERA) conference, which brings together stakeholders in science education research.

Can cyber insurance combat cyber crime?

In a world where so much information is stored digitally, cyber attacks that hold computers hostage can be incredibly damaging. **Dr Jason Nurse**, from the Institute of Cyber Security for Society at the **University of Kent**, UK, and **Jamie MacColl**, from the UK's **Royal United Services Institute**, are investigating whether companies can use cyber insurance to help mitigate the threat from cyber criminals.

Dr Jason R.C. Nurse

Institute of Cyber Security for Society (iCSS) and School of Computing, University of Kent, UK

Jamie MacColl

Royal United Services Institute (RUSI), UK

Field of research
Cyber Security

Research project
Investigating the effectiveness of cyber insurance against ransomware attacks

Team members
Gareth Mott, Sarah Turner, James Sullivan, Pia Huesch, Anna Cartwright and Edward Cartwright

Funder
UK National Cyber Security Centre (NCSC)

PROFILES

Talk like a ...

cyber security expert

Cyber attack — an attack against a computer system

Cyber security — protecting computer systems and networks from cyber attacks

Insurance — when a provider agrees to compensate an individual or organisation for a future loss, in return for a regular payment. With cyber insurance, a provider agrees to compensate an individual or organisation if they suffer a cyber attack

Malware — software designed to perform an unauthorised action that will impact the security of a computer system

Policy — a set of guidelines

Policymaker — someone who creates policies

Ransomware — malware that blocks access to a computer system until a ransom is paid

Stakeholder — a person with an interest (a 'stake') in a particular topic

Think tank — a group of experts on a particular topic that engage with researchers and policymakers to provide policy advice

In the 17th century, pirates would kidnap wealthy merchants and demand money in exchange for their safe release. Today, the ransoming of digital data by cyber criminals is far more likely. Cyber security researchers Dr Jason Nurse, from the University of Kent's Institute of Cyber Security for Society (iCSS), and Jamie MacColl, from the Royal United Services Institute (RUSI), have teamed up to analyse the impacts of ransomware, investigate whether cyber insurance can protect organisations from these attacks, and influence national cyber security policies.

What are the impacts of ransomware?

"Ransomware is a form of cyber attack," explains Jason. "A cyber criminal installs malware on a computer system, which blocks access to the computer and all the data contained on it. The criminal then demands money and only removes the malware once the computer owner has paid the ransom." As today's world is driven by technology, if organisations lose access to computer files or networks it can have disastrous impacts.

Beyond the cost of the ransom demand (which can range from hundreds to millions of pounds), there are additional factors that make the cost of a ransomware attack much greater. "The company will lose money during the time it can't access the computer network," says Jason. "There will also be damage to the company's reputation, negative impacts on individuals' well-being, and potential harm to wider society." For example, a ransomware attack on the UK's National Health Service (NHS) in 2017 had huge knock-on impacts as hospitals were unable to access patients' medical records, which meant doctors could not carry out medical procedures.

"Educational institutions are increasingly being hit by ransomware attacks," says Jason. "They hold a huge amount of sensitive data about

students and, unfortunately, their cyber security is often not very strong, so criminals see them as a good target." In 2022, several UK schools were attacked, with the hackers leaking highly confidential documents containing children's data online.

Cyber criminals do not only target organisations, they also attack individuals. Your phone contains a wealth of information about you that hackers would love to get hold of. Not only could a ransomware attack result in you losing access to your phone and accounts, but criminals could also steal your data (and that of all your contacts) and sell or share it online.

What are the challenges of researching ransomware attacks?

Jason, Jamie and their team are investigating the nature and impacts of ransomware attacks, in the hope of informing public policies that will help protect organisations. However, this is not always an easy task. "There are three main challenges to analysing ransomware: underreporting, long-term impacts and non-financial costs," says Jason.

Underreporting happens because many ransomware incidents are never revealed by the companies affected. "To avoid bad publicity, many companies quietly pay off the criminals and struggle to recover by themselves, without ever reporting the attack," says Jamie. "If we don't learn of these incidents, we don't learn from them either." Even when attacks are reported, the long-term impacts are difficult to measure. Impacts can continue for months as the organisation recovers, so it is hard to quantify the total cost of the incident. Non-financial costs are also difficult to measure, especially the impact on people's psychological well-being. "How do you put a number on the level of stress faced by a teenager who knows their personal details have been shared online, a doctor who can't help their patients or an IT professional working long shifts to recover a company's computer systems?" asks Jason.

Can cyber insurance protect against ransomware attacks?

If you have phone insurance, you pay a small amount of money every month to an insurance provider and, in return, they will pay to repair your phone if it breaks. Cyber insurance works in the same way: organisations pay a regular fee to an insurance provider, who will cover the cost of the ransom, should the organisation be attacked by cyber threats such as ransomware.

> **"It's important to bring in different perspectives from different areas of expertise so we can find the best solutions to the challenge."**

Jason and Jamie work with people involved in all aspects of preventing and responding to ransomware attacks, including insurance providers, cyber security experts and companies who have been attacked. "We hold workshops that bring these stakeholders together, to learn how ransomware is impacting organisations and how insurance can help to reduce this threat," says Jamie. "It's important to bring in different perspectives from different areas of expertise so we can find the best solutions to the challenge."

So far, the team has discovered that the process of applying for cyber insurance encourages companies to improve their cyber security. "The cost of insurance depends on the likelihood that the provider will need to pay out in the future," says Jason. "For instance, your home insurance will be cheaper if you have good locks on your doors and windows and live in an area with low crime, because your provider knows it's less likely that you will be burgled." It is the same concept for cyber insurance: if a company has good cyber security, they are less likely to suffer a ransomware attack, so their cyber insurance will be cheaper. "We have discovered that companies improve their cyber security before applying for cyber insurance, as this reduces the cost of insurance," says Jamie. "In this way, cyber insurance has a positive impact on cyber security."

However, the overall effect of cyber insurance on cyber security is less clear when criminals' motives are also considered. "There is anecdotal evidence that cyber criminals deliberately target companies that have cyber insurance, because they know the ransom will be paid by the insurance provider," says Jason. In the same way that ancient pirates attacked wealthy merchant ships rather than poor fishing boats as there was a greater chance of the ransom being paid, modern cyber criminals attack organisations that are more likely to pay up. "This means that, when all factors are considered, it's hard to know whether cyber insurance has a positive or negative effect on cyber security."

How can this academic research influence policy?

The collaboration between iCSS (an academic research institute) and RUSI (a government think tank) is key to Jason and Jamie's project, as it ensures the research findings are used effectively to improve society. "Our relationship allows us to produce robust research that addresses significant societal issues and communicate our policy recommendations directly with policymakers," explains Jason.

Not only does Jamie contribute to the team's research, but in his role at RUSI he is also responsible for communicating the project's findings with the government and wider public, by engaging with the UK Parliament and the media. "I recently presented the results of our ransomware research to members of a UK Parliamentary Committee, to help them understand the issues around cyber security and ransomware," he says. "In this way, our research is influencing important policy decisions around cyber security at a national level."

About *cyber security*

Ever since computers entered mainstream use, criminals have been attacking them. "Today, a ransomware attack happens every 14 seconds!" says Jamie. As society relies so heavily on computers and digital information, protecting them from cyber attacks is a vital task. Cyber security does not just depend on the computer scientists and software engineers who design the technical solutions to protect computers; it also requires an understanding of human behaviour.

"It is important to apply theories and approaches from psychology to better understand and find solutions for cyber security problems," explains Jason. "By working with psychologists, we can learn why people make the decisions they do (such as opening unknown files or clicking on dodgy links) and use this knowledge to help make policy recommendations."

Cyber security is a constant 'arms race' between security systems and cyber criminals, as each side develops more sophisticated software to outwit their opponents. "Artificial intelligence (AI) will inevitably provide the next challenge and opportunity for both sides," says Jason. "While cyber security experts can use AI to detect and defend against cyber attacks, cyber criminals can use it to scale up their attacks. I've already seen ChatGPT used to launch cyber attacks."

To inform the future of cyber security, Jamie recommends learning from past experiences. "There is an ongoing lack of awareness and investment in cyber security," he says. "Many of the current challenges we face are new versions of old cyber security problems, so understanding the future requires studying the past."

Jason and Jamie's tips *for staying safe online*

- Be careful what you share online. Even if later removed, anything posted online is potentially accessible forever, and criminals can harvest it for information.
- Check the privacy settings of your devices, applications and social media accounts. Who can see what you post online? What information are technology companies collecting about you?
- Protect all your accounts with strong, distinct passwords. Using a password manager is helpful for this.
- Use two-factor authentication to add additional protection to your accounts and devices, by requiring two forms of identification to access them.

Pathway from school to *cyber security*

- Computer science, information technology (IT), software engineering and maths are very useful subjects for a technical career in cyber security.
- There is also a range of non-technical careers in cyber security that rely on people with backgrounds in psychology, politics, international relations and public policy, so studying any of these could also lead to a career in the field.
- You can gain practical hands-on experience in cyber security while at school through programmes such as Hack the Box (**www.hackthebox.com**), where you can learn how to identify weaknesses in computer systems by penetration testing (also known as 'ethical hacking').
- The CyberFirst programme (**www.ncsc.gov.uk/cyberfirst**) run by the National Cyber Security Centre (NCSC) has a range of activities, resources, courses and competitions to help you stay safe online and inspire you to consider a career in cyber security.
- The NCSC also offers bursaries and apprenticeships to support students hoping to pursue a career in cyber security: **www.ncsc.gov.uk/cyberfirst/bursary-and-degree-apprenticeship**

Explore careers in *cyber security*

- "So much of today's world is built on technology, and this technology needs to be secured," says Jason. "This means there is an ever-increasing range of career opportunities in cyber security."
- Technical careers in cyber security include systems and security architects (who build secure computer systems), penetration testers (who try to ethically hack into computer systems to test a network's defences) and IT security managers (who oversee an organisation's digital systems).
- You do not need a technical computer background to have a career in cyber security. The human component of cyber security means that, with a background in behavioural psychology, you could work to understand how and why people make decisions that harm computer systems. Or, if you are interested in geopolitics, you could work in cyber threat intelligence. Governments and think tanks also need people interested in the intersection of cyber security and public policy to create policies that protect organisations from cyber attacks.
- Prospects provides information about careers in cyber security, including the qualifications you may need and the salary you can expect: **www.prospects.ac.uk/job-profiles/cyber-security-analyst**

Meet *Jason*

I've always been interested in computers and technology. Who would've thought that one day we would be able to find the answer to any question on our phone, or take phone calls from our watch? Technological progress is fascinating!

It's important to know that you don't have to be great with computers and technology to work in cyber security. I studied maths, accounting and business studies at school, then accounting and computer science at university. After graduating, I worked as an auditor, and it was only later that I realised I wanted a career in cyber security.

I am inspired by the reality that my work makes the world a safer place. Cyber attacks are constantly evolving, so cyber security must always be one step ahead. This means I'm constantly addressing new challenges, and it's exciting to work in a field that's so dynamic.

Alongside conducting academic research, I also work in industry. I'm the director of science and research at a cyber security company, where I lead a team of scientists conducting innovative work to inform the company's products. Although we produce technology outputs, most of the researchers are psychologists, highlighting the importance of understanding human behaviour for addressing cyber security challenges. It's great to have a practical application for my research and to know that I'm helping to ensure that computer systems are built in a robust and evidence-based way.

Jason's *top tip*

Find a good mentor. It is important to have people you can look up to and who can guide you through your studies and career.

Meet *Jamie*

I have a bachelor's degree in war studies and a master's in international relations and politics, which might not seem like an obvious route to a career in cyber security. However, these subjects link to geopolitics and, as it's important to understand nations' motives when preparing for global cyber threats, many of my classmates now also work in the field, particularly in cyber threat intelligence.

While at university, I did an internship at a small cyber threat intelligence company. The experience was hugely valuable as I learnt practical skills, such as writing daily intelligence reports, and I contributed to genuine research projects. Wherever possible, I highly recommend that students seek out meaningful internships.

I enjoy conducting research interviews with experts from government and industry and bringing these people together through workshops to learn from their experiences. In addition, I like the intellectual exercise of figuring out complex policy challenges.

Music is my passion and has always been an important part of my life. I have been in a band, the Bombay Bicycle Club, since I was 14. We still play together, touring and performing as professional musicians. Playing live music on stage is the best feeling ever! Having two careers keeps me very busy, and while they are completely unrelated, my experiences as a young musician taught me how to communicate with the media – a valuable skill that helps me in my current role as I educate the public about cyber security research.

Jamie's *top tip*

You don't need to have everything figured out when you're 18 – or even when you're 30! Instead, be open to any experience that comes your way and accept that life might not follow the path you expect.

Technology is everywhere in our lives © Joe Edmunds

Using adsorbents to help society

You will likely have heard of absorption before, but have you heard of adsorption? At the **University of Notre Dame** in Indiana, USA, **Dr Yamil Colón** is a chemical and biomolecular engineer studying this important chemical process. His work could help make huge breakthroughs in healthcare, climate change, environment and water scarcity research.

Dr Yamil Colón

Assistant Professor of Chemical and Biomolecular Engineering, College of Engineering, University of Notre Dame, USA

Fields of research
Chemical and Biomolecular Engineering, Computational Materials Discovery and Design

Research project
Modelling adsorption of gases onto solid materials to find new adsorbent materials

Funders
US National Science Foundation (NSF), US Department of Energy (DOE), American Chemical Society Petroleum Research Fund

This work is supported by the National Science Foundation under the NSF CAREER Award CBET-2143346. The contents are solely the responsibility of the authors and do not necessarily represent the official views of NSF.

PROFILE

Talk like a ...

chemical and biomolecular engineer

Absorption — a type of sorption process whereby particles are transferred into another material

Active learning (AL) — a special case of machine learning in which an algorithm can pick the data it wants to learn from and question a source of information

Adsorption — a type of sorption process whereby particles are transferred onto the surface of another material

Machine learning (ML) — computer systems that can learn and adapt without following explicit instructions from humans

Porous — having tiny spaces or holes through which liquid or gas can pass

Potable water — water that is fit for humans to consume

Scarcity — the state of being in short supply

Sorbent — a substance which can collect molecules of another substance by either adsorbing or absorbing them

Sorption process — a process where one substance becomes attached to another

While they sound extremely similar, absorption and adsorption are two different things. Both are sorption processes, where one substance attaches to another. However, unlike absorption, where particles are transferred into another material, adsorption is where particles attach themselves to the surface of another material.

Adsorption allows various molecules to be both captured and separated from each other. "Adsorption is a common process in our everyday lives," says Dr Yamil Colón, based at the University of Notre Dame's College of Engineering. "It occurs in many industrial and biological settings, such as drug delivery, power production and water harvesting, to name a few."

An everyday example of adsorption is the use of small, silica gel packets that are often found in the packaging of electronics, shoes or food. Silica gel adsorbs water and can, therefore, prevent these items from becoming damaged by moisture.

Why is adsorption important?

Adsorption can be used to do far more than just adsorbing water; amazingly, it can be used to diagnose and help with healthcare problems too. "In relation to healthcare, new adsorbents can help with diagnostics and delivery," explains Yamil. For example, electronic nose devices – commonly called eNose devices – use adsorption to analyse the molecules in a person's exhaled breath to see if it contains compounds connected to disease. "There are also adsorbents capable of holding and releasing molecules of interest, like drugs, which can have an important impact," Yamil adds.

How could adsorbents benefit the environment?

Adsorbent materials can also have a huge environmental impact. Firstly, since sorbents can separate molecules from each other, finding new sorbents that can do this as efficiently as possible will reduce the energy needed for each separation. "This directly translates to less use of fossil fuels," says Yamil.

Adsorption can also help with carbon capture, as new sorbents can capture carbon directly from the air and from gas streams. Carbon capture is when carbon dioxide, produced by the burning of fossil fuels or other processes, is trapped and stored before it can affect the atmosphere. This technique can help mitigate the effects of global warming.

In addition, some adsorbent materials can even harvest water from the atmosphere. The ability to capture and produce potable water can make a significant difference in areas with frequent droughts and scarce water sources. "New adsorbent materials can also be used to remove pollutants from contaminated water streams," explains Yamil.

What is Yamil working on?

Yamil is the director of a research group which is examining the interactions among different types of gases and the materials they attach – or adsorb – onto. Yamil is hoping his research will lead to two things: a better understanding of the adsorption process and the discovery of new adsorbent materials.

Why is it important to identify new adsorbents?

For adsorption to help with healthcare and environmental issues, scientists need to develop new adsorbent materials that are more energy efficient. "The identification of new adsorbents is critical to technological advancements in healthcare, climate change and water scarcity," explains Yamil. "Adsorption can be leveraged to meet modern day challenges around carbon capture and water security, but we need new sorbents that can meet performance demands around capacity and energy efficiency."

Understanding the adsorption process

Another one of the research group's goals is to better understand what happens during adsorption. To do this, Yamil's team is aiming to create a universal gas adsorption model that accurately predicts the amount of gas that is adsorbed on a material. "Such a model will be an important engineering design tool to advance work in drug delivery, power production, energy storage, atmospheric water harvesting and carbon capture technologies," says Yamil.

> ***"Adsorption is a common process in our everyday lives and in many industrial and biological settings."***

How does the team do this research?

Yamil and the team use data science, statistical mechanics, powerful computational modelling tools and machine learning (ML) tools to learn more about adsorption and discover and design new porous materials.

The team is looking at porous materials because the pores provide surface area for adsorption to take place within the material, and they can store significant amounts of gas. "Interactions in the pores can also be tailored to attract certain gases over others and can, thus, also be used as a platform to perform separations," Yamil adds. This is where the molecular modelling tools come in. Scientists use molecular models, also known as molecular simulations, to analyse how molecules work and fit together and learn more about their functions, processes and pathways. "We use molecular simulations to characterise and design the interactions happening in the pores, for applications in hydrogen storage, methane storage, water harvesting and gas separations," Yamil explains.

The team then combines these molecular simulations with active learning (AL) algorithms. These AL algorithms allow the researchers to develop models that describe a complete adsorption space, even with only a small amount of data from that space. "AL can direct our molecular simulations to the most important conditions (temperature, pressure and composition) to develop accurate models that describe a relevant adsorption process," explains Yamil.

What is new about this technique?

Molecular simulations to describe adsorption can require lots of data. Simulating various molecules at different temperatures, pressures and other operating conditions is an extremely resource-intensive process. This is why the research group's idea to combine these molecular simulations with AL algorithms is very important.

"We have demonstrated that the combination of AL with our molecular simulations can help save on the number of simulations needed to show the properties we are looking for – such as temperature, pressure and compositions," says Yamil.

What else does the project team do?

The research group also prioritises outreach and education components, so that people outside of the group can learn about its work. "This includes increasing machine learning literacy through course design; hosting middle school STEM teachers on campus to create course materials on probability and statistics; and translating middle school course materials into Spanish for dissemination in the local community and in Puerto Rico," explains Yamil.

Next up, Yamil and the team are hoping to develop more complex models, specifically ones that will allow them to look at what happens to the adsorption material as adsorption takes place.

About *chemical and biomolecular engineering*

If you enjoy chemistry, physics, biology and mathematics and are interested in learning how things work on a small scale, then you should consider a career in chemical and biomolecular engineering. Chemical and biomolecular engineers solve some of the world's most urgent problems by applying techniques from engineering, biochemistry, cell biology and organic chemistry at the molecular level. These engineers work on anything from how to develop green energy and move away from fossil fuels, to finding new technologies to probe our brains and understand how diseases affect our bodies.

A desire to help others is important for working in this area, as your research might impact thousands of lives. "The most rewarding thing about research in this field is the prospect of developing technologies with great societal impact by improving fundamental scientific understanding," says Yamil. For example, as our world is becoming more affected by climate change, chemical and biomolecular engineers are striving to find new ways to supply adequate fresh water to water-scarce communities and create novel methods of transport that do not harm the environment.

The next generation of chemical and biomolecular engineers will also have a wealth of new research opportunities and questions available to them, thanks to machine learning and artificial intelligence tools. "Two major areas of opportunity are in bridging the time and length scales of multiscale research efforts and in developing new ways to leverage the algorithms in experimental and processing settings," says Yamil. It is an exciting time to consider a chemical and biomolecular engineering career!

Pathway from school to *chemical and biomolecular engineering*

- At school and post-16, take classes in chemistry, physics, mathematics and biology. Choose a university degree such as chemical engineering, chemistry, biomolecular engineering, biochemistry or biomedical engineering. These courses will have a core curriculum, but Yamil suggests taking advanced probability and statistics classes as well, if you can.
- While science and mathematics classes are important, Yamil also strongly recommends taking classes geared towards improving oral, visual and written communication skills. "These can be classes like theatre and creative writing," he explains. These classes will give you the skills to explain your scientific findings to others, so that your work can be used and applied to different fields.
- During your undergraduate degree, try to get some professional experience in the field. Find work or volunteer as an intern or research assistant in a lab. Ask your lecturers if they know anywhere you could get some hands-on experience.
- To work in chemical and biomolecular engineering research, you will need to complete a PhD after you finish your undergraduate degree. Yamil, for instance, completed his PhD at Northwestern University before joining the Notre Dame faculty.
- Read this article to find out how Yamil got to where he is today: **www.nd.edu/stories/from-here-to-there**

Explore careers in *chemical and biomolecular engineering*

- The Institution of Chemical Engineers has a brilliant page about chemical engineering for prospective students, including 'Meet the Engineer' interviews, FAQs and information on choosing the right university programme. It also provides a list of all its accredited chemical engineering degrees worldwide: **www.icheme.org/education/whynotchemeng**
- Visit Yamil's research group website (**www.computationalnano.org**), which contains interesting and informative recordings of webinars and presentations, to get an idea of what it is like to work in chemical and biomolecular engineering.
- The College of Engineering at Notre Dame University runs the Engineering Exploration High School Camp. This day camp introduces students in grades 10 to 12 to a broad range of engineering topics through hands-on activities: **engineering.nd.edu/news/first-engineering-exploration-summer-camp-for-area-high-school-students**
- Visit the Chemical Engineer website for news and information about jobs in chemical, biochemical and process engineering: **www.thechemicalengineer.com**
- According to Indeed.com, the average annual salary in the US for either a chemical engineer or a biomolecular engineer is around $94,000.

© 3d_illustrator/Shutterstock.com

Q&A

Meet *Yamil*

Who or what inspired you to become a scientist?

My parents inspired me to become a scientist. My mother was a middle school science teacher, and my father was a digital editor for a local television station in Puerto Rico. I got to see and experience science and engineering through seeing them both in their professions.

What experiences have shaped you as a scientist?

The experiences that have shaped me go back to my high school teachers and mentors who supported me. Their passion for science and their quality as human beings have been deeply influential. They also showed me you can do what you think is cool, while at the same time looking to answer questions to meet technological needs for societal challenges.

What does being awarded the NSF Faculty Early Career Development Program (CAREER) award mean to you?

Being awarded the NSF CAREER award is a vote of confidence from the scientific community that the ideas we are exploring and our outreach efforts are important. It is also a credit to the members of my group, who have put in a great amount of work to make what we do possible.

What other achievements are you particularly proud of?

I am also proud of being invited to the 2023 National Academy of Engineering Japan-America Frontiers of Engineering Symposium. I believe addressing today's scientific challenges requires an international collaborative effort, and this conference will be instrumental in helping establish a network of collaborators to do just that.

What are your ambitions for the future?

My ambition is to lead international teams and research efforts to address society's most pressing technical challenges, while educating the next generation of researchers.

Yamil's *top tips*

1. Get involved in different kinds of research so you find what you like and what you don't.

2. Look to enrich your learning with classes outside of your major; these will help you appreciate different perspectives and points of view. That type of learning can be invaluable and the source of new and creative approaches.

How can first-year STEM university students be better supported?

Going to university is a huge change from going to high school. At the **University of Pittsburgh at Greensburg** in the US, biologists **Barbara Barnhart** and **Dr Olivia Long** are using their **Science Seminar** programme to ease this transition for first year students studying biology, chemistry and biochemistry degrees.

Barbara Barnhart

Instructor of Biology, University of Pittsburgh at Greensburg, USA

Field of research
STEM Education

Funder
US National Science Foundation (NSF)

Dr Olivia Long

Associate Professor of Biochemistry and Biology, University of Pittsburgh at Greensburg, USA

Fields of research
Biology, Biochemistry, STEM Education

Funders
NSF, Eberly Foundation

Research project
Developing Science Seminars for first-year STEM college students
www.nsf.gov/awardsearch/showAward?AWD_ID=1458289

PROFILES

Talk like a ... STEM educator

Autopsy — a surgical examination of someone's body after they have died, with the aim of learning the precise cause of death

Cite — make reference to

Credibility — the quality of being trusted or believed

Holistic — considering and treating the whole of something, not just a part of it

Peer leader — for Science Seminar, an older student who acts as a mentor and role model for a younger student

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

The first year of university can be overwhelming for anyone – from learning how to manage your workload to making new friends and cooking for yourself. At the University of Pittsburgh at Greensburg, Barbara Barnhart and Dr Olivia Long are providing students with vital skills to help them adjust to this new phase of education and develop a better sense of community with their peers. Called Science Seminar, their project aims to help STEM students transition to college life.

What is Science Seminar?

Science Seminar is designed to improve students' academic, study and interpersonal skills. To decide which skills to focus on, Barbara and Olivia identified areas of weaknesses from their previous STEM students. "With this information, we created a variety of objectives, ranging from communication skills and respect for community, to leadership skills and critical thinking," says Olivia. The programme also aims to inform students about what facilities and services are available to them on campus, as well as getting them to think about their personal and career goals.

How do the seminars work?

The Science Seminars are taught by full-time science faculty members who are familiar with the courses students are taking and will need to take in the future. The faculty member, along with a peer leader, provides mentorship and academic advice.

The seminars revolve around group projects, discussions and case studies on STEM-related issues. The goal is for students to consider scientific issues from multiple points of view and develop their critical thinking skills. "These activities give students opportunities to exchange ideas, learn from each other, communicate and develop teamwork skills," explains Olivia. Ideally, the seminar will be a space where students feel comfortable sharing their ideas and asking questions.

What do the seminars teach students?

The course aims to teach a variety of skills, ranging from library and research skills (to ensure students can assess the credibility of what they read and dissect complex texts, such as scientific reports) to study-management skills (such as time and stress management and academic planning).

These skills are taught from a holistic and practical perspective, taking the wider student experience into account.

"For example, to teach time management, we ask students to break down a typical day and week, including class time, study sessions and personal time (for hobbies, meals, exercise, etc.)," explains Olivia. "This encourages them to be realistic about their time and establish a healthy work-life balance." Students also identify distractions that limit their productivity – and ways to minimise these. Library and research skills cover areas such as knowing how to reference and cite authors properly, being able to discern between

© Rawpixel.com/Shutterstock.com

reliable and unreliable sources of information, accessing scientific literature and giving accurate evidence-based arguments when writing scientific essays and reports.

"Students struggle with the overwhelming amount of information available online, so it is vital that they develop the skills in evaluating the credibility and reliability of the sources," says Olivia.

How are these skills taught?

The scope of objectives Olivia and Barbara are aiming for students to achieve demands a range of learning experiences. One of their methods is a focus on case studies, looking at specific issues in detail. One such case study revolves around the non-fiction book '*The Immortal Life of Henriette Lacks*', written by Rebecca Skloot. The book describes the life of African American woman Henrietta Lacks, who, during surgical procedures for cancer in 1951, had tissue samples removed from her body without her knowledge or consent.

Less than a year after being admitted to hospital, Henrietta died. During an autopsy on her body, more tissue samples were taken – this time, without her family's knowledge or consent. Research conducted on Henrietta's cells contributed to an astonishing number of medical breakthroughs, but this was all done without her permission and so raises ethical questions.

"The overarching question that the book proposes is 'who owns your biological tissues?'," explains Barbara. "By using case studies and books that highlight social scientific issues, we are teaching students that there are many factors and stakeholders that need to be considered when looking at STEM issues."

What do students learn from studying this?

Studying and discussing such thought-provoking content teaches students that STEM issues are not straightforward; different perspectives and nuanced arguments must be considered. The impact of this learning can be seen when comparing student responses from before reading the book and participating in class discussions, to afterwards. Students who had changed their position were more likely to use evidence for that position when writing their final assignment, showing stronger research skills.

"On the other hand, those who did not change their position did not have appropriate evidence and gave their opinion without much support," says Barbara. This shows that considering counterarguments is a vital part of learning and leads to an improvement in critical analysis and written communication skills.

How is Science Seminar forward focused?

Looking ahead to students' futures, the programme also involves career exploration, prompting students to investigate graduate school, job requirements, and concepts such as job shadowing.

Olivia explains, "By encouraging students to consider their career options early on, they have a longer timeframe to make informed decisions, set meaningful goals, and take relevant action to shape their educational and professional paths."

The focus on potential careers includes a visit from the on-campus Career Service Office. First-year students answer a career aptitude questionnaire to help them discover possible jobs that match their skills and interests. "It is common for students to receive external influence, such as family expectations, when choosing their career paths, especially in science or medical fields," says Olivia. "However, it is important for students to have a clear understanding of the requirements and expectations of their desired graduate programmes early on in their undergraduate careers. Without this knowledge, they may not be adequately prepared to meet the specific admission criteria."

With this focus on preparation in mind, Barbara has created the 'Five Graduate School Requirements' assignment. Students choose five graduate schools and research their pre-requisite (essential) requirements, along with any other requirements, such as volunteer experience. "This serves as a helpful tool for identifying the requirements and accomplishments needed for admission to graduate school," explains Barbara. "For example, some graduate programmes require applicants to have accumulated 500 or more hours of patient care contact hours. Attaining this level of experience solely during the final year of undergraduate studies would be quite difficult. The assignment helps students to see the importance of taking proactive steps as early as their first year of undergraduate studies."

How successful is Science Seminar?

The programme's success is reflected in the significantly higher first to second year retention rates for students in Science Seminar compared to students who do not take the class. "81.8% of Science Seminar students return as science majors as sophomores, compared to only 51.8% of non-Science Seminar students who are retained as science majors," says Olivia

"The seminars make students feel valued as individuals, and their learning experiences become more meaningful and relevant to their interests and goals," says Olivia. This results in students becoming more focused and engaged with their learning.

Science Seminar objectives:

- Develop the academic skills necessary to make a successful transition to college life
- Identify and use campus facilities, resources and services that enhance academic and personal success
- Exhibit a sense of community among class members based on mutual respect, challenge and support
- Demonstrate computer literacy and effective oral and written communication skills
- Explore one's own identity by reflecting on your own beliefs, values, attitudes and aspirations
- Demonstrate leadership and conflict resolution skills
- Demonstrate critical thinking and problem-solving skills
- Demonstrate awareness, respect and appreciation for differences among people
- Demonstrate the ability to work independently and collaboratively
- Establish personal and career goals

This material is based upon work supported by the NSF under Grant No. 1458289. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

About *biology*

Biology is the study of all living things: their structures, processes, life cycles, habitats, and abilities to adapt and evolve. Biologists can study anything from how microscopic cells are created and work together, to how populations of animals evolve over time.

Studying all life on planet Earth makes for a very broad and wide-ranging subject area, and interdisciplinary research is critical in this field. Biology is often combined with engineering, medicine, psychology, sociology, chemistry, physics or mathematics, so that scientists can tackle complex, real-world problems.

"STEM issues are not 'black and white': there are many factors and stakeholders that need to be considered," says Barbara. Studying biology involves looking at problems from different perspectives to come up with scientific and ethical solutions.

Why is interdisciplinary research important?

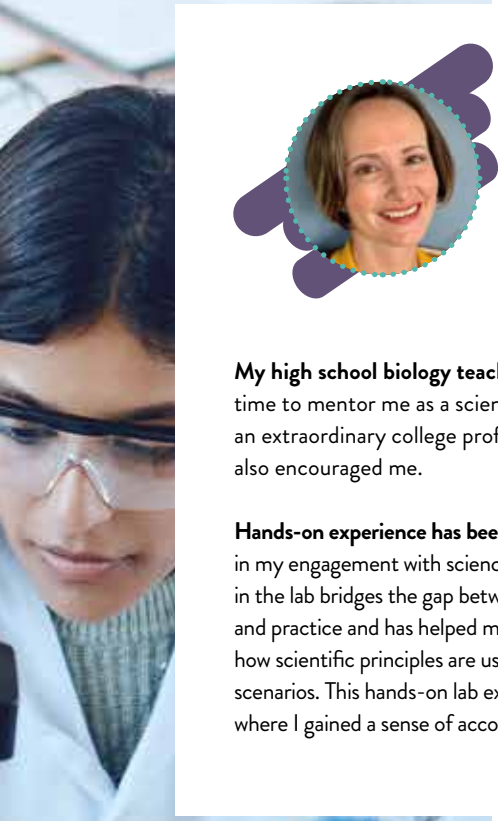
"Many scientific challenges, such as understanding the mechanisms of disease, addressing climate change, or developing sustainable technologies, require a multidimensional approach," says Olivia. "By bringing together experts from various disciplines, interdisciplinary collaborations enable a comprehensive understanding of these complex problems and foster the development of holistic solutions."

Pathway from school to *biology*

- To learn more about possible careers in biology, have a look at the 'Biology: Changing the World' project – also available as a phone app – which celebrates the work of different scientists in the field worldwide: **biologyheritage.rsb.org.uk/bcw-interviews**
- Barbara suggests exploring the Best Colleges website: **www.bestcolleges.com/careers/science-and-engineering/biology**. As well as useful information on what biologists can do and which areas they might work in, this website gives estimated salaries for different biology jobs according to years of experience.
- Olivia recommends having a look at the University of Pittsburgh at Greensburg 'Career Ready' page, which is "designed to assist high school students in exploring different career paths, developing professional skills, and making informed decisions about their future": **www.greensburg.pitt.edu/student-resources/career-services/career-ready**
- According to Career Explorer, the average salary for a biologist in the US is around $82,600 per year. "When it comes to pursuing a career in biology, students need to be realistic regarding salaries for biologists and the education required. There are many different fields of biology. Those who are pursuing a career with a bachelor's degree will make less money than those with a doctorate degree," Barbara adds.

Explore careers in *biology*

- At high school and post-16 years, choose biology, chemistry and physics classes. "If you have the option, take a statistics course and mathematics courses beyond algebra," says Barbara.
- Choose a university course in biology or a subject related to biological sciences. "Biology is such an expansive field of study that the courses you choose really depend on what you wish to do as a career. You will have foundation courses including genetics, ecology and biochemistry. From that point, you will have a number of paths to consider such as molecular biology, microbiology or conservation ecology, for example," says Barbara.
- Barbara recommends choosing a programme that can provide you with opportunities for independent research and internships. "Those are the experiences that will help you to decide which career in biology you wish to pursue," she says.
- Get work experience in a laboratory. If you are interested in conservation biology or ecology, contact a local conservation charity and ask if they take volunteers.
- "Many careers in biology require education beyond a bachelor's degree," says Barbara. You are likely to need a master's degree or PhD if you want to work in scientific research.
- The University of Pittsburgh at Greensburg runs a fully funded summer camp that gives students entering 9th grade an immersive opportunity to explore science, sustainability, mathematics and engineering fields. Students are selected through being recommended by their principal, teacher or guidance counsellor. Find out more: **www.greensburg.pitt.edu/community/summer-science-and-math-experience**



Meet *Olivia*

My high school biology teacher took the time to mentor me as a scientist, and I had an extraordinary college professor who also encouraged me.

Hands-on experience has been essential in my engagement with science. Working in the lab bridges the gap between theory and practice and has helped me understand how scientific principles are used in practical scenarios. This hands-on lab experience is where I gained a sense of accomplishment. While performing experiments, analysing data and drawing meaningful conclusions, I became more self-reliant, developed resilience when facing challenges, and helped build my scientific identity.

The worst advice I've been given is that as a female, I wasn't 'worth' the time and effort to train as a scientist as I would eventually leave the field to have a family. The future of science lies in embracing diversity and ensuring equal opportunities for all. Women play a crucial role in shaping the scientific landscape, bringing unique insights and perspectives that drive meaningful advancements.

One of my proudest career achievements thus far is successfully completing my PhD. This significant milestone represents years of dedicated research, rigorous study and the mastery of specialised knowledge in my field.

Statistics in STEM suggest that I shouldn't be where I am today. I am a first-generation, low-income, rural, female student who pursued degrees in STEM. This helps me to connect on an individual level with the students I am trying to engage and the struggles they may encounter. Personally, I have experienced the importance of an authentic connection and its impact on the success of a student. I am dedicated to understanding and enhancing the undergraduate educational experience for first-generation, rural, or underrepresented science students. I seek to improve access to resources, mentorship opportunities and hands-on experiences for these students.

Meet *Barbara*

I was inspired to become a scientist by a combination of courses, teachers and professors. My high school chemistry teacher encouraged me to complete an independent experiment that showed me that I was capable of being a woman in science. In college, I had two professors who also encouraged me to push myself to realise my true potential. I have also learned as much from interactions with students as they have from me.

I was a first-generation, financially needy, rural student. I had a family member who advised me to become a waitress or secretary because my divorced mother would not have the financial means for me to attend college. I began to look at those career paths, but, fortunately, my mother had a boss who gave much better advice. He believed that anyone could go to college and helped my mother and me to find scholarships and grants that brought that dream of college to reality.

My proudest career achievements are receiving the Outstanding Teaching Award at my college and the Chancellor's Distinguished Teaching Award from my university.

In the future, I aim to continue to provide a supportive and inclusive teaching environment for students to learn and develop their STEM identities.

Barbara and Olivia's *top tips*

1. Develop active reading habits like highlighting key points, taking notes, asking questions, and summarising and reflecting on the main ideas and arguments. This helps you retain information and promotes critical thinking.

2. Ask questions to challenge assumptions, clarify understanding and uncover hidden biases or gaps in reasoning. This helps develop a deeper understanding of the subject matter.

3. Participate in discussions and engage with others who may have different viewpoints. Be open to constructive criticism and actively listen to other perspectives. Regularly reflect on your own thinking processes and biases.

Fabulous and fashionable: how the FAB Lab is encouraging fashion entrepreneurs

Fashion can give you the confidence and power to express yourself. Around the world, people use clothes, jewellery and accessories as a way to celebrate their individuality. But for young fashion enthusiasts who want to create their own fashion business, the competition is tough as high-street brands and online retailers dominate the market. To help them forge a path into the world of fashion, **Dr Samii Kennedy Benson** has established the **FAB Lab**, a business incubator at **Southern University and A&M College** in Louisiana, USA, that gives young fashion entrepreneurs the skills they need to be successful.

Dr Samii Kennedy Benson

Assistant Professor of Apparel Merchandising and Textiles, Department of Family and Consumer Sciences, Southern University and A&M College, Louisiana, USA

PROFILE

Field of research
Fashion Entrepreneurship

Research project
Developing a business incubator to help fashion students gain the skills they need to successfully run their own businesses

Funders
US Department of Agriculture (USDA) – 1890 Institutional Teaching; Research and Extension Capacity Building Grants (CBG) Program, Grant Number 2021-38821-34718

Talk like a ...

fashion entrepreneur

Apparel — any form of clothing or garment

Business incubator — an organisation or programme that gives new businesses the support and resources they need to grow and become successful

Draping — the process of positioning and pinning fabric on a mannequin to create prototypes of new clothing designs

Entrepreneur — someone who starts their own business

Entrepreneurial self-efficacy (ESE) — an individual's confidence in their own ability to create a successful business

Merchandising — the methods used to promote and sell products to customers

Pattern drafting — the process of using body measurements to create pattern pieces which become the foundation for designers to create garments

As humans, we can all feel the need to express ourselves, to share our feelings with others and to show the world who we are. Some of us find expression through playing music or painting pictures. Others express themselves through the work they do or the relationships they have with friends and family.

One of the most vibrant and versatile forms of self-expression is fashion. Clothes and accessories can provide the colours, textures and patterns that we need to express our personalities and interests. From a t-shirt promoting your favourite band to a colourful pair of mismatched socks, you can use fashion to help you find and fit into your community, or to celebrate your individuality and stand out from the crowd.

Around the world, people also use clothing and jewellery to express their heritage and celebrate their cultural identity. Blending traditional items with modern fashion trends can help people find their own unique style. This process of curation and creation can be empowering. Designing bespoke garments, creating new outfits or altering unwanted items can help you take control of your identity. For some people, designing and creating clothes is more than a passionate hobby, it is a career aspiration.

However, starting a fashion business is not easy. Budding apparel and fashion design entrepreneurs face stiff competition from high-street brands and online retailers. To succeed in the world of fashion, these up-and-coming entrepreneurs need more than just a steady hand and a good fashion sense; they also need business skills and support from others in the industry.

This is why, at Southern University and A&M College in Louisiana, Dr Samii Kennedy Benson has established the Fashion and Apparel Business Laboratory (FAB Lab), where she hopes to help fashion students gain the skills they need to run their own businesses.

What is the FAB Lab?

The FAB Lab is a business incubator to help up-and-coming fashion entrepreneurs. Specifically focused on fashion design and apparel entrepreneurship, it provides a nurturing environment in which Samii's students can develop their fashion

FAB Youth attend the FAB Lab summer camp

skills and hone their business ideas. "Business incubators are important because they help budding entrepreneurs turn their ideas and concepts into a viable enterprise," explains Samii.

Why did Samii establish the FAB Lab?

As an assistant professor of apparel, merchandising and textiles, Samii teaches students who are interested in fashion, design and entrepreneurship. "At the beginning of each course, I always ask my students what they hope to do after graduation," she says. "Overwhelmingly, most say they want to start their own fashion business." Samii established the FAB Lab because she wanted to give her students the knowledge, skills and tools they would need to become successful entrepreneurs and run successful fashion businesses.

"The FAB Lab is particularly focused on supporting women and minority entrepreneurs," says Samii. "In addition to the difficulties that come with running a business, they often face unique challenges, due to racism and gender bias, that can get in the way of their success." While current trends indicate there is a rise in entrepreneurship among people of colour, minorities still make up just 15% of small business owners in the US.

Many factors contribute to the lack of entrepreneurial activity among women and people of colour. "One significant factor is a lack of entrepreneurial self-efficacy (ESE)," explains Samii. "This refers to an individual's level of self-confidence in their ability to succeed in creating a successful business. If someone has low ESE, they may not believe that creating and owning their own business is a realistic option for them." Evidence indicates that entrepreneurship educational initiatives, such as the FAB Lab, can help to improve ESE among people from minority backgrounds. Samii's goal is for the FAB Lab to instil confidence in her students, leading to greater diversity and representation among fashion entrepreneurs.

How does the FAB Lab train its entrepreneurs?

The FAB Lab runs four schemes, which not only support university fashion students, but also provide fashion and business training for local middle and high school students and community members. FAB Fellows are students enrolled in the apparel, merchandising and textiles degree programme at Southern University and A&M College. Each year, five FAB Fellows are supported as they develop their own fashion line or apparel business. This support comes in the form of mentorship, financial aid, access to design spaces and equipment in the lab, and the opportunity to market and sell their products at a local boutique retail store.

The FAB Fellows also help to lead the summer camp for FAB Youth. Each summer, ten local middle and high school students from minority backgrounds attend the 4-week-long camp, where they learn practical textile and fashion skills, as well as entrepreneurship skills, which give them an important head start as they embark on their journey into the fashion industry.

Any students or community members interested in fashion can become FAB Entrepreneurs. The FAB Entrepreneurs programme offers workshops, short courses and networking events to promote and support fashion entrepreneurship in the local area. These events include lectures and panels featuring guest speakers from the fashion industry, fashion showcases (where students share their collections) and portfolio reviews. To ensure the programme is accessible to the wider community, events are held in the evening and at weekends, as well as during normal working hours, with some events also accessible online. FAB Entrepreneurs can formalise their fashion training through the FAB Certificate, a series of fashion design and apparel entrepreneurship courses for which participants can earn college credits, covering topics such as the fundamentals of fashion entrepreneurship, creating a business plan, and digital communication and marketing.

The wealth of opportunities available through the FAB Lab provides budding fashion entrepreneurs with the skills needed to turn their talents for design into a viable business. These include design skills, such as sketching and making mood boards to spark new ideas, creation skills, such as sewing techniques, pattern drafting and draping to bring their creations to life, and entrepreneurial skills, such as business planning and brand development to share their designs with the world.

What successes has the FAB Lab had?

The initiation of the FAB Lab has been a great success. The first group of FAB Fellows helped to establish the FAB Lab by assisting in the design of the lab space and helping to select the new equipment. These students then worked in the lab space to perfect their business concepts, create samples for their fashion lines and conduct market research for their new fashion brands. "Two of these FAB Fellows have already launched their fashion brands and have begun selling their clothes to clientele!" says Samii.

"This summer, the FAB Lab hosted its first FAB Youth summer camp for middle and high school students," she continues. The campers learnt entrepreneurial skills, including what characteristics they need to run their own business, as well as fashion design skills, such as sketching and sewing. "On the last day, participants took part in a fashion show to display the clothes that they made during their time at the camp." Through the FAB Lab, Samii is inspiring and supporting the next generation of fashion entrepreneurs.

About *fashion entrepreneurship*

"Small fashion and apparel businesses represent what's new and innovative in the fashion industry," explains Samii. While famous high-end fashion designers and large-scale high street bands might dominate the scene, small fashion businesses can be more creative in their marketing and designs as they have more freedom to 'think outside the box'.

How can small fashion businesses address the challenges facing the fashion industry?

"Smaller brands are leading the way when it comes to social responsibility and environmentally sustainable practices," says Samii. The negative impacts of 'fast fashion', such as the poor working conditions of people working in textiles factories and the huge amounts of waste caused when poor quality cheap clothing is worn a few times then thrown away, are beginning to take centre stage. Small fashion businesses can promote ethical and sustainable business models, helping to tackle the fashion industry's greatest issues. "I enjoy encouraging students to not only think creatively about fashion, but also to critically analyse the fashion industry's ethical issues," says Samii. "These include labour practices, environmental concerns, lack of diversity and the promotion of an unobtainable beauty ideal."

FAB Fellow Tiffany presents her designs

Pathway from school to *fashion entrepreneurship*

- The best thing to do if you are interested in fashion entrepreneurship is to get creating! "Get a sketch book and start drawing designs," advises Samii. Use YouTube tutorials to teach yourself to sew, knit or crochet and start making things. "You don't need fancy equipment like a sewing machine and new fabric to start making clothes," she says. "I taught myself to sew by hand with a needle and thread using my old clothes for my fabric!"
- If your high school offers classes in textiles, fashion, design, consumer sciences or business studies, take these to start learning about fashion and entrepreneurship. Other useful subjects include art (to enhance your creativity and learn new artistic techniques), mathematics (to learn the skills for dealing with your business's finances) and English (to improve your communication skills).
- At college or university, take courses in fashion merchandising (to learn about the retail side of the fashion industry), apparel construction (to learn the basics of sewing clothing) and the history of art and fashion (to explore how and why fashions change).
- If you do not want to go to university, fashion internships and apprenticeships are a great way to gain hands-on, real-world experience of working in the fashion industry.

Explore careers in *fashion entrepreneurship*

- Explore the world of fashion by reading fashion magazines and websites. Samii recommends Teen Vogue (**www.teenvogue.com**), Fashion Bomb Daily (**fashionbombdaily.com**), Business of Fashion (**www.businessoffashion.com**), The Cut (**www.thecut.com**) and Women's Wear Daily (**www.wwd.com**).
- Reach out to fashion professionals. Ask them questions about their career and whether they can provide you with work experience opportunities.
- If you are more interested in the merchandising side of fashion, pursue an entry level position in fashion retail. "If you are motivated and determined, you can successfully climb the career ladder to end in the area of the fashion industry that suits your skills and interests," says Samii.
- The Art Career Project (**www.theartcareerproject.com/fashion-careers**) provides information about the range of career opportunities in the fashion industry, from designer to dressmaker, merchandiser to model, with details about what each role entails and how to get started in the field.

Meet *Samii*

My passion for fashion and love of sewing began in childhood when I taught myself how to design and sew clothes for my Barbie dolls. The movie *Mahogany*, starring Diana Ross as a famous Black woman fashion designer, was also inspirational for me as a young girl. As a teenager, my parents gave me a sewing machine and sewing lessons, and I began to make my own clothes. I was voted 'Best Dressed' in my senior year of high school due to my one-of-a-kind outfits!

For me, fashion is more than just clothing on a hanger or accessories on display. I view fashion not only as a multi-billion-dollar industry but as a cultural art form worthy of study, and it has been my outlet of expression for as long as I can remember.

I always wanted to be a teacher, like my mother, and I also wanted to work in the fashion industry in some capacity. While in high school, I took a fashion merchandising course at a local vocational school and realised I could combine my career aspirations of fashion and teaching. After an undergraduate degree in family and consumer sciences education, I taught child development, food science, interior design, and (my favourite!) fashion design and merchandising at a high school. After gaining a master's in textiles, merchandising and interiors, I taught apparel, sewing and fashion courses at a community college. I returned to university to pursue my PhD in apparel, merchandising and design, for which I explored the experiences of Black female fashion design entrepreneurs for my dissertation research.

Teaching sewing is my calling, and it has always been my personal mission to 'spread the joy of sewing!' I established my sewing studio, *That's Sew Samii*, to teach the valuable skill of sewing to people of all ages. My entrepreneurial journey has included many changes, including moving from a brick-and-mortar sewing studio to teaching individuals online, as I have learnt that a successful business knows when and how to pivot to best meet the needs of its clients.

Growing up as a young Black girl, I didn't have many examples of someone who looked like me doing what I wanted to do. I hope to be the best role model for my daughters and my students, because representation matters. I want to show them that it is possible to do and be whatever they want in life, whether it's in the fashion industry, or otherwise, no matter what they look like or where they come from. If I can do it, then surely, they can do it too!

Samii's *top tips*

1. **Be self-motivated:** find that drive inside of you that helps you to keep going when things get tough.
2. **Do your best in school:** being the best student that you can be will open doors for your future.
3. **Follow your passion:** if you are not passionate about your work, you will never enjoy it, but if you do what you love, you will never work a day in your life.

Meet *FAB Lab students*

"The FAB Lab taught me the skills to take my ideas from paper to the fashion marketplace and gave me the opportunity to showcase my designs at conferences, which lead to scholarships and future employment opportunities. I plan to continue designing and selling my faith-based urban clothing line and I hope to provide an outlet for women and children to express their faith through fashion."

Tiffany, FAB Fellow

"During the FAB Lab summer camp, I most enjoyed making a newspaper dress as I was able to use my creativity to design and create it. I benefited from my involvement in the FAB Lab because I can now make lots of fashionable things. In the future, I would like to have my own fashion business and I hope to become a famous fashion designer."

Zakiah, FAB Youth

"I have greatly benefitted from the resources I receive as a FAB Fellow. The FAB Lab has given me the space and supplies to create my designs and fulfil my entrepreneurial goals. I really enjoyed helping to lead the FAB Youth summer camp, teaching middle and high school students how to sew and be a creative entrepreneur. My dream is to provide fashion-forward, sustainable clothing for plus-size women."

Darlynn, FAB Fellow

"I enjoyed the FAB Lab summer camp as I learnt how to sew, so now I can create the designs in my sketch book. My favourite activity was the end-of-camp fashion show where we got to show off what we designed! In the future, I hope to become an art teacher and professional nail artist with my own nail salon."

Honour, FAB Youth

How we read: the neuroscience behind literacy

Reading and writing are essential skills for modern life, but how often do you think about how your brain processes written information? Based at the **University of Alberta** in Canada, **Professor Jacqueline Cummine** is helping decode how we read – in particular, the important role of our senses – and using these findings to help people who struggle with literacy skills.

Professor Jacqueline Cummine

Faculty of Rehabilitation Medicine – Communication Sciences & Disorders, University of Alberta, Canada

PROFILE

Field of research
Cognitive Neuropsychology

Research project
Exploring how the brain is wired to enable literacy, with the aim of supporting people with literacy difficulties

Funder
The Natural Sciences and Engineering Research Council of Canada (NSERC)

Talk like a ...

cognitive neuropsychologist

Cognitive — relating to conscious mental activities, such as thinking, reasoning, remembering and using languages

Larynx — also known as the voice box, allows air to pass from the throat to the trachea (the windpipe)

Literacy — the ability to read and write

Neuroplasticity — the ability of the brain to change its activity by reorganising its structure or functions

Neuroscience — the science of the structure and function of the nervous system and brain

Phoneme — a distinct unit of sound that makes up words and language

Speech motor planning — the ability to come up with an idea, plan how to express it, and then say it

Understanding and using written language is a highly sophisticated skill, and humans are the only animals able to do so to any degree of complexity. Most of us can process series of symbols with near-infinite possible combinations, and understand what they signify, all in milliseconds. However, humans have only been reading for around 5,000 years, which is not enough time for this skill to evolve – which means we read using parts of our brains that likely evolved for something else.

Understanding how we read is important, particularly to provide solutions for those with lower reading and writing abilities. "Literacy skills have a profound impact on a person's life," says Dr Jacqueline Cummine, a professor at the Faculty of Rehabilitation Medicine – Communication Science and Disorders at the University of Alberta. "Even subtle differences in literacy skills can significantly affect academic success, employment and mental well-being." Jacqueline is studying how we read, how these systems can break down, and how to best help people with reading, hearing or speech impairments to read and write effectively.

Spoken word, written word

"Different sensory systems work together to help us understand the different symbols in a text," says Jacqueline. "Our eyes, ears and touch systems all play important roles in reading." While it is obvious how sight is involved in reading, research has also uncovered the important roles of hearing and touch. Words are made up of small units of sound called phonemes – with specific sounds associated with /ch/ or /b/, for instance – which we need to be able to identify accurately to read proficiently. This identification is most rapid if we can 'hear' the sounds in our heads, which are learnt through listening and speaking. Touch is also involved. "Part of our reading proficiency is linked to our ability to say words and sounds quickly and fluently," says Jacqueline. "We use touch to rapidly and accurately move our tongues, lips and larynx to produce sounds."

Typically, we learn how to read well after we learn how to speak, and it is theorised that reading builds upon our speech production system. "Imagine a child learning to read, being taught by an adult," says Jacqueline. "The adult shows the child letters and tells them how they sound, and the child repeats them. Once they have identified these letters correctly, the child can put them together to form words." For instance, the

© Igor Link/Shutterstock.com

phonemes /c/, /a/ and /t/ can be put together to make /cat/. Because this process is taught through speech, learning how to identify words and letters is closely linked to learning how they sound and how they are produced. "This understanding led us to make some predictions about the role of the mouth in reading processes," says Jacqueline. "For example, we investigated how if adults held large lollipops in their mouths, their silent reading abilities were impacted, as they were faster to distinguish real words from nonsense words. We're continuing to explore these fascinating effects!"

Reading impairments

People can have difficulty reading for several reasons. For instance, if a person is born deaf and, therefore, never learns how letters and words 'sound', it can be very challenging to learn how to read, as the combinations of letters that make up words can appear arbitrary. Reading also becomes progressively more difficult to learn as we age, as our brains become less adaptable. "If someone is not given a chance to learn to read at a young age, it becomes harder to learn later in life," says Jacqueline. "It's still possible but can be very difficult."

Issues with reading can also be cognitive. "Another type of breakdown can happen in the brain," explains Jacqueline. "This is when, even if the senses work well, the brain cannot process the information correctly, leading to difficulties with word recognition, decoding or production." A common example of this is dyslexia, a learning-based disorder where individuals have trouble learning to read, despite having no intellectual challenges.

In the brain

Jacqueline's lab uses several different technologies to look inside the brain and see what effect different stimuli have on neural activities. "We use functional magnetic resonance imaging (fMRI) and functional near infrared spectroscopy (fNIRS)," says Jaqueline. "When a part of the brain is 'working', it uses oxygen, which it receives from blood, and both methods detect this process – fMRI through radio frequency waves, and fNIRS through light waves. When these waves hit molecules such as oxygen, they bounce back to our sensors in an altered state, which we can decode." A third technique, diffusion tensor imaging (DTI), measures how water moves through white matter tracts, which are special pathways that connect and coordinate communications between different parts of the brain.

> ***"If someone is not given a chance to learn to read at a young age, it becomes harder to learn later in life. It's still possible but can be very difficult."***

"There are three main parts of the brain that we are interested in," explains Jacqueline. "The inferior frontal gyrus stores information about speech motor plans and sequences for articulation. The temporo-parietal region helps join phonemes together. And the inferior temporal gyrus is important for letter and word recognition." For example, when a child learns to read the word /red/, they will likely already be familiar with how it sounds; therefore, the inferior frontal gyrus already has this information. Then, the inferior temporal gyrus stores information about the individual letters, and the temporo-parietal region helps link the letters to sounds and words. "When we put the whole word together in print, we connect the three systems," says Jacqueline. "These connections are strengthened over many years of learning, leading to a fluent and efficient system to promote communication."

Into the real world

Jacqueline's team has designed and tested two training programmes to help adults with dyslexia improve their reading. "In skill-based training, we focus on teaching skills important for reading, like understanding phonemes and letter patterns, and knowing how to read and spell long or difficult words," explains Jacqueline. "In goal-based training, individuals set their own goals associated with reading and we design activities to help them achieve them." Before and after the training, Jacqueline's team tested reading performance and measured brain activity using fNIRS. "We found that both programmes improved reading performance in adults with dyslexia," says Jacqueline. "We also saw changes in brain activity, providing evidence for neuroplasticity following intensive training."

Jacqueline's team is now working on providing resources for adults with literacy challenges to train and enhance their reading skills, to improve their daily well-being. "We also want to go beyond reading-specific skills," says Jacqueline. "For example, a lot of adults with reading impairments feel anxiety in social situations, so also addressing these wider goals could have far-reaching effects on day-to-day living." The team is partnering with a non-profit organisation to pilot this work in the community, helping to improve people's everyday lives.

About *cognitive neuropsychology*

Cognitive neuropsychology is the study of how the structure and function of the brain relates to our perception of the world, reasoning, memory and language. This involves studying brain activity directly, examining the effects of neurological illnesses and how certain stimuli affect performance of specific tasks. Jacqueline explains more about her field:

"For me, the greatest reward of my role is getting to work with and training new scientists. There are so many curious minds out there that just need a supportive space to explore their questions. The enthusiasm and energy that emerging scientists bring to research is a constant rejuvenation!

"An ongoing challenge for my field is trying to buck the status quo. There is a lot of 'tradition' with regards to ideas and approaches, which I feel can sometimes impede our ability to move science forward efficiently. I hope that initiatives to increase diversity and inclusion can alter this trajectory, making space for a more holistic, flexible and nuanced approach to advancing knowledge.

"For aspiring cognitive neuropsychologists, I recommend getting into a lab as soon as possible. Volunteering with professors or graduate students is the best way to learn about a topic and understand what it 'looks like' to be in a particular field. Every lab has a different environment, a unique approach to science, varying interpersonal dynamics, and so on. The hands-on experience of being in a lab, or several over time ideally, is an invaluable opportunity."

Pathway from school to *cognitive neuropsychology*

- At school and post-16 years old, subjects such as biology, chemistry, psychology, mathematics and English or other languages can provide a good foundation for an appropriate undergraduate degree at university.
- Jacqueline says that many areas of study can lead to a career in her field, including undergraduate degrees in psychology, linguistics, neuroscience, biology and medicine.

Explore careers in *cognitive neuropsychology*

- The University of Alberta holds an annual Program Discovery Week, which the Faculty of Rehabilitation Medicine participates in, to help high school students learn about the many varied programmes the university offers: **www.ualberta.ca/admissions/undergraduate/tours-and-events/program-discovery-week.html**
- Knowing Neurons is an award-winning neuroscience website run by young neuroscientists. It includes articles, videos and information about neuroscience careers and events: **knowingneurons.com**
- Individuals with degrees in cognitive neuroscience can work in many areas, including academia, healthcare, government, industry and education, to name just a few.

© Roman Samborskyio/Shutterstock.com

Meet *Jacqueline*

When I was at the University of Saskatchewan, a close friend encouraged me to pursue a career in science. She's an amazing human and was incredibly supportive. Funnily enough, she herself chose a different career, but I became a scientist!

My own experiences have informed my research. I have had personal struggles with reading new and complex words, and have suffered hearing loss. For many years, I hid both these challenges and was embarrassed about their consequences in social scenarios, such as not knowing or mishearing the words that people used. But now, I embrace how my experiences with these struggles have provided me with novel insights into potential underlying mechanisms and strategies for overcoming these challenges.

> ***Our world is increasingly reliant on the written word, be it emails, texts social media and so on.***

An example of how my experiences have shaped my research is when I read '*A Hitchhiker's Guide to the Galaxy*' by Douglas Adams. I found myself unable to retain much information about the story, because so many characters had bizarre and unique names – Zaphod Beeblebrox, for instance. Because I couldn't 'say' the names, it was like I was 'seeing' them for the first time every time they appeared in the book, which disrupted my ability to comprehend the story. This has informed our research that explores reading comprehension and reading fluency for individuals with reading impairments.

I aspire to help make life easier for adults with reading challenges. Our world is increasingly reliant on the written word, be it emails, texts social media and so on. In an ideal world, we would have accessible remediation programmes for all those who have difficulties with reading.

Modelling minds: can computers mimic human intelligence?

The human brain is often referred to as the most complex device known in the Universe. It gives rise to the amazing abilities of the human mind, including our capacity for intelligence. For many years, psychologists and neuroscientists have sought to uncover how the mind functions, while computer scientists have attempted to reproduce human-like capabilities in machines. Collaborations between these disciplines have resulted in computational models that are helping scientists to uncover the secrets of the mind and impart this intelligence to computers.

Are computers smarter than you? Or are you smarter than computers? Well, it depends on how you define what it means to be 'smart'. In recent years, we have developed computers that greatly exceed our own abilities in many tasks. For example, computers can perform thousands of calculations per second, meaning they can solve some mathematical problems far more quickly and accurately than humans. And computers have beaten human world champions at games of chess and go. But does this mean they are smarter than us? While computers can outperform humans in many domains, including arithmetic, object recognition and some aspects of language processing, no machine yet exists that can match human performance in *all* these domains. We are still unique in our ability to use our intelligence to adapt to a remarkably wide range of tasks.

What is human intelligence?

As humans, we have the unique ability to make connections between things we have previously learnt and use those to solve challenges in new situations. For example, your language processing abilities mean that if you hear an unfamiliar word, you can often infer its meaning from the context of the conversation, or know to look it up in a dictionary. While many animals display specialised forms of intelligence, humans are flexible and creative when dealing with unfamiliar circumstances as our brains have the capacity for adaptive learning. Your brain is also incredibly efficient, running on only about 20 Watts of power to control your whole body and mind – similar to a standard lightbulb!

Understanding how the human brain functions so efficiently and flexibly remains one of the greatest mysteries of science. Psychologists, neuroscientists and computer scientists hope to uncover this mystery with the help of computational models.

What are computational models?

A mathematical expression, or **function,** transforms an input to an output. For example, the function +10 transforms the inputs [1, 2, 90] to the outputs [11, 12, 100], by adding 10 to each input. An **algorithm** links multiple functions together in a rule-based sequence. For example, the algorithm +10, ×2 is a different algorithm than ×2, +10 (because 1 + 10 = 11, 11 × 2 = 22; while 1 × 2 = 2, 2 + 10 = 12). A **variable** is an element of a function that can be assigned different **parametric values.** For example, if the function is +b, then the variable can be set to b = 1 (the parametric value is 1, transforming [1, 2, 90] to [2, 3, 91]) or b = 314 (the parametric value is 314, transforming [1, 2, 90] to [315, 316, 404]). **Computational models** are built from mathematical functions linked together into algorithms with specific parametric variables. A model can then be used to explore how the assignment of different inputs to its variables affect its behaviour. This is helpful, as models can quickly become too complex to solve mathematically; in this case, a computer program can be run to see how the model behaves with different inputs.

Talk like a ...

computational cognitive neuroscientist

Cognition — the mental process of acquiring, evaluating and/or using knowledge

Cognitive task — an activity that involves processing and/or recalling information

Computational model — the expression of a set of mathematical functions or algorithms in the form of a computer program designed to emulate a natural process, such as cognition

Intelligence — the ability to acquire and flexibly apply knowledge and skills to solve new problems

Language processing — the ability to formulate and understand language

Mind — the expression of cognition implemented by a physical system, such as the brain

Neuron — a nerve cell that transmits messages to and from other neurons and other cells in the body and brain

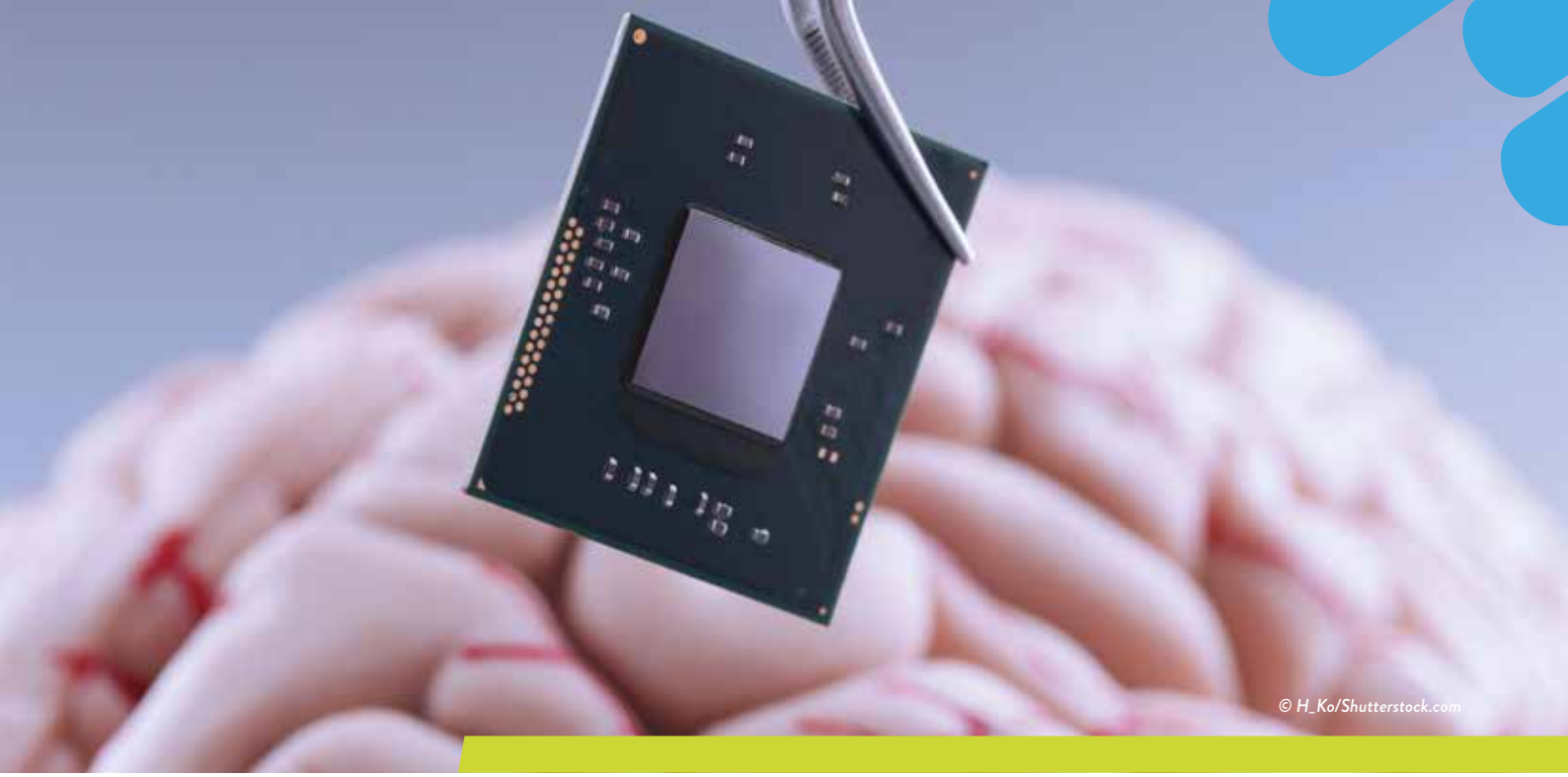
Neuroscience — the study of tthe nervous system, including the brain

Stimulus — any input that can be processed to generate an internal or external response by the nervous system

Synapse — the part of a neuron that communicates its signals to other neurons

How do scientists use computational models?

Scientists aim to create computational models that reproduce the patterns of behaviour exhibited by what is being modelled, such as human performance of a task. This involves exploring which functions to use, how to arrange these functions into algorithms, and testing different parametric values for each variable until the behaviour of the model matches the observed data (for example, how



someone behaves when performing a task). Once scientists have created a model that replicates observed data, it can be used to generate predictions of future data.

Computational models allow scientists to investigate how different components in complex systems interact by providing a way to mathematically express their theories of how they think the system may behave. When creating a computational model, scientists are forced to acknowledge all the assumptions on which their theory relies, as each assumption must be translated into an element of the model. Then, scientists can use the model to test the behaviour of the system, and any assumptions about it, by observing the system 'in action' in the form of a computer simulation. One common objection to computational models is that they make too many assumptions. However, the advantage of a model is that it makes those assumptions clear and concrete. One way to think about them is as hypotheses made precise by the model, that can then be tested in future experiments.

Weather forecasting: an example of a computational model

Some natural phenomena, such the orbit of the Earth around the Sun, can be well described by a single mathematical equation. This means that scientists can accurately calculate the position of our planet for any given day in the future. However, other phenomena, such as weather systems, involve complex dynamic interactions among a vast number of components (such as the molecules in the atmosphere) that cannot be simplified into a single equation to describe the behaviour of the full system. This means it is hard to predict future weather. However, scientists can tackle this complexity using computational models to forecast what the future weather might be like.

Weather is influenced by a variety of variables, including land temperature, air temperature, humidity, air pressure, wind speed and direction, and topographic features (such as mountains and water bodies), all of which influence the interactions among the molecules that make up the weather. Meteorologists create computational models of weather systems to examine how these different variables lead to different weather outcomes. For example, it is likely to rain if the temperature and humidity are both high but then the temperature drops, or if the wind carries air over a water body and then over a mountain. These statements can be converted into algorithms and combined to create computational weather models.

These models are tested on previously observed weather data. For example, if yesterday's conditions of temperature, pressure, humidity, etc., are entered into the model as inputs, and the model produces an output that matches today's weather, then this indicates that the functions, algorithms and parametric values used in the model do a good job of predicting future weather. If they do not accurately predict the weather, they can be modified in an effort to improve the model, which can then be used to better predict future weather.

Predictions of complex phenomena are always challenging, in part because there are so many interacting variables, and because uncertainties in the model can multiply and overwhelm initial assumptions. This means that computational models of the weather can make predictions with high accuracy for only a short distance into the future. For example, while the forecast of the weather in two hours' time or tomorrow will be fairly accurate, a prediction of the weather in ten days' time is likely to be less accurate.

Modelling minds: a computational model of the human brain

Like the weather, the functioning of the mind involves highly complex interactions over a vast number of parts - in this case, the neurons and synapses of the brain. To better understand these, scientists attempt to recreate them using computational models. At their core, computational models of the human brain are algorithms, many of which are designed and trained with the goal of reproducing intelligent human behaviour. For example, a language processing model could use the previous words in this sentence to predict what word is going to appear _____. If you guessed 'next' or 'here', then the language processing mechanisms in your brain work in a similar way to most people's when making language predictions. These mechanisms are accurately predicted by many existing computational models of language processing.

Computational cognitive neuroscience is an emerging field that seeks to understand human cognition by building computational models that express theories of how the brain gives rise to cognition. To test whether these models operate in a similar way to the human mind, scientists compare their performance with findings from work in cognitive psychology studying human performance.

For over a century, psychologists have conducted experiments that use cognitive tasks to characterise the mental functions people use when solving problems, generating a wealth of data on human perception, memory, decision making, language learning, emotions, etc. These experiments have also revealed how the mind functions when the brain is disrupted, for example through injury or psychiatric conditions. In more recent years, neuroscientists have uncovered the structural organisation of the brain at different scales, from individual neurons to large brain regions. They have characterised the functions that different brain structures perform in tasks such as perception, memory and movement.

These data are combined to build computational models of the human brain, enabling scientists to test how the operation of different brain mechanisms gives rise to different psychological functions. Understanding this relationship will not only provide insights into how disruptions to brain functions can be corrected but will also help scientists understand how to better implement intelligence in machines.

Examples of computational cognitive neuroscience models

Reward learning and prediction error

Many of the ways in which we exhibit intelligence are not exclusive to humans. Animals are born into complex environments where they learn about potential rewards (e.g., food) and dangers (e.g., predators). While millions of years of evolution have programmed certain instincts into animals (such as 'seek food' and 'run away from mouths with lots of sharp teeth'), they also exhibit the capacity for adaptive learning.

The ability of (human and non-human) animals to adaptively learn how to behave can be simplified into a computational model. For example, a simple model might simulate how an animal holds a recent sensory input (such as a scent) in its memory, then uses that information as a predictor for the outcome of what happens next. For example, if the animal smells a berry then finds food, or smells a fox then almost gets eaten, then the next time the animal encounters that same sensory input, it can predict that a similar outcome will occur and either approach the reward or avoid the danger. When the prediction is accurate (the animal smells another berry then finds more food), this strengthens the association between the input stimulus and the response, while if the prediction is wrong, the association is weakened. Over time, the animal adaptively learns what stimuli will lead to different rewards and adversities.

However, while this sort of stimulus-response learning can lead to efficient behaviour, it can be inflexible. What happens if the circumstances change (e.g., the bush contains no more berries)?

Cognitive control and flexibility

While such association formation is a powerful and ubiquitous form of learning in animals, it can also be inflexible. Humans exhibit a remarkable ability to flexibly overcome such associations — and even basic reflexes — when needed. For example, if a person is instructed *not* to scratch an itch, they are able to do so (though it may be uncomfortable!). Simple as this seems, it shows that with a simple instruction, a person can instantaneously overcome the millions of years of evolution that produced that reflex (even reptiles scratch itches!). This ability is not matched by any other species.

This flexibility can also be demonstrated using a simple cognitive experiment known as the Stroop task. In this task, a person is shown the written name of a colour displayed in a different colour than the word (e.g., GREEN). If they are told to respond to this stimulus out loud, they almost universally do so by reading the word (i.e., saying 'green') and almost never report the colour. This is because the association between the written word and verbal response is useful in many settings (e.g., reading) and so is strongly learnt, much like the association of the location of a berry bush with reward.

However, if the person is instructed to report the colour (i.e., say 'red'), they can do so (although they may find it challenging). This relies on the capacity for cognitive control — the ability to take an instruction (or internal intention) and use it to override a strongly learnt association or instinctive reflex to achieve a different goal (e.g., naming the colour or not worsening the inflammation causing the itch).

Cognitive control and task evaluation

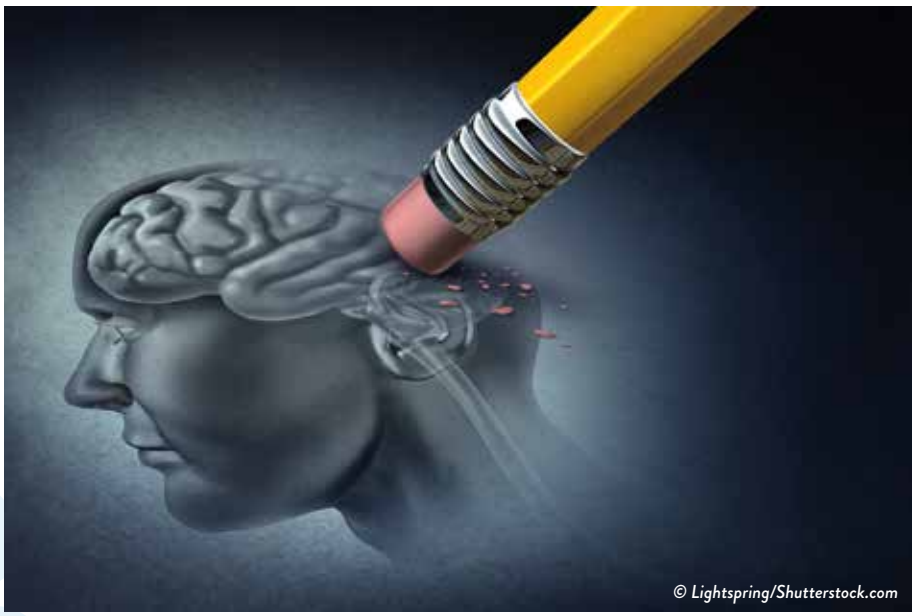
When performing tasks, there is a trade-off between flexibility and efficiency. The human brain has a remarkable ability to switch between these two modes of operation, from efficient behaviour based on past learning to more flexible forms of behaviour that, although not quite as efficient, allow us to adapt quickly and effectively to new situations. One example of this is typing: almost anyone can quickly learn to use a keyboard, by typing one figure at a time. This works for any keyboard, whether it is on a computer or a piano, but it is not very efficient. With practice, people can learn to use a particular keyboard with tremendous efficiency, but they might not transfer very well to a different keyboard (e.g., from a computer to a musical instrument). One of the primary functions of cognitive control is to decide when each type of behaviour is best, and guide behaviour accordingly.

Human memory

Memories are characterised by their duration (**long-term** memories last days to years; **short-term** memories last minutes to hours; **working** memories are actively maintained in your current awareness) and function (**episodic** memories are recollections of specific events, such as your tenth birthday party; **semantic** memories are ones about regularities and structure in the world, such the knowledge that birds fly while mammals (for the most part do not).

Different kinds of memory serve different functions. For example, episodic memories will help you make predictions in specific contexts, while semantic memories will help you make predictions across a wide variety of contexts. Long-term memories contain information that is occasionally useful and can be retrieved from storage when that information is relevant, while short-term memories contain information that was recently accessed and still needed for the current task (either newly encountered information or a long-term memory that was recently retrieved from storage). Another important role of cognitive control is to decide which type of memory is most useful for a particular problem, and to use that memory system for storage and/or retrieval.

Computational modelling has been useful in gaining a better understanding of how the brain carries out all these functions, from reward learning to the role of cognitive control in the use of memory for planning and problem solving, all of which contribute to the capacity for intelligent behaviour.



Tools for computational modelling

The hardware and software used for computational models of intelligence are continually evolving as computer scientists, psychologists and neuroscientists work to solve problems and drive progress in the field. As computational practices change over time, with computational tools and programming languages continually evolving, computational modelling faces many challenges regarding the development of models in each field.

Ideally, there would be a universal programming language that could be used by all researchers who were interested in building models of the human brain and intelligence, which would make it easy for them to exchange and make use of each other's models. In reality, there are many different types of models in use, written in many different programming languages, and each research project must consider trade-offs and make decisions that will influence the investigation and resulting computational models.

To ensure continued progress in the field of computational cognitive neuroscience, it would be helpful if these many different computational models of human brain function and intelligence could be brought into the same framework so they could be evaluated, deconstructed and recombined into new models. PsyNeuLink is one experimental effort to do this.

What is PsyNeuLink?

PsyNeuLink is a platform developed by researchers in the Neuroscience of Cognitive Control Lab at Princeton University in the US. It is a modelling environment for building the computational models used by neuroscientists, psychologists and computer scientists to explore brain functions and psychological behaviours, and their relationship with artificial intelligence. In PsyNeuLink, scientists can construct different components of their models and integrate them into the modelling environment, where they can run the models as simulations and analyse their interactions. The aim is to develop a common repository for model-sharing, allowing scientists working on different computational cognitive neuroscience projects to access the best modelling tools for uncovering how the brain gives rise to human intelligence, and how this can be implemented in machines.

Pathway from school to *computational cognitive neuroscience*

- As computational cognitive neuroscience is an interdisciplinary field combining psychology, neuroscience and computer science, a degree in any of these subjects could lead to a career in the field.
- A wide range of other subjects is also relevant for uncovering the mechanisms behind intelligence. For example, members of the Neuroscience of Cognitive Control Lab come from many different backgrounds, including machine learning, data science, electrical engineering, medicine, physics and philosophy.
- Coding and computer programming are key skills for developing computational models, so look for free online tutorials where you can learn, such as Code Academy: **www.codecademy.com**

© Gorodenkoff/Shutterstock.com

Neuroscience of Cognitive Control Lab
Princeton Neuroscience Institute,
Princeton University, USA

Fields of research
Neuroscience, Psychology, Computational Modelling

Research project
Investigating the neuroscientific and psychological mechanisms behind cognition and intelligence using computational models

Funders
US National Institutes of Health (NIH), National Science Foundation (NSF), Office of Naval Research

Websites
ncclab.princeton.edu
www.psyneulink.org

PROFILE

Meet *members of the Neuroscience of Cognitive Control Lab*

Dr Javier Masís

Role: Postdoctoral researcher

Fields of research: Neuroscience, Cognitive Science

I have always been very curious about the world. I am not only interested in science, but also in history, politics, literature, art and music. I chose to become a researcher in the hope of contributing a little bit to humanity's body of knowledge.

As a cognitive scientist, I study learning and treat it as an investment, and I investigate when it is worthwhile to make that investment and when it isn't. For example, if your teacher suddenly announces there will be a test tomorrow, you could lose sleep trying to review all your notes, but you might not be able to retain much information. However, if your teacher announces there will be a test next week, then you could dedicate some time every day to revise and you are likely to learn and remember more, so your learning investment will be more worthwhile.

I use a combination of simulations and behavioural measurements during games to study how we decide to invest in learning. I've found that this decision depends on several factors, such as how much time you have to learn, how fast you think you'll learn, what your reward for learning will be and how far in the future it is. I've also discovered that there's a key trade-off between satisfying immediate needs (i.e., instant gratification) and how quickly you'll learn a new task.

Science is about communication and collaboration, plus some well-intended conflict, to resolve which theories are correct and which are incorrect. I love working with my colleagues as there's nothing more satisfying than encountering curious, energetic people who want to work together to figure out cool stuff!

You don't have to actually study brains to 'study the brain'. Research is so vast that there are many different ways to contribute to the field of neuroscience. For example, while I am technically a brain scientist, I hardly ever deal with specific brain regions. Instead, I study the problems the brain solves, which generates important findings for other scientists who study the brain itself.

When I'm not studying neuroscience, I play drums in an alternative rock band. We are called Burne Holiday (www.burneholiday.com), we have been playing together since college and we now have two albums and several cool cover songs. I love playing with the group!

Javier's *top tip*

Cultivate your curiosity! The world becomes a much more interesting place when you start wondering how things work and why things are the way they are.

Tyler Giallanza

Role: Graduate student

Field of research: Cognitive Psychology

I was interested in many topics when I was younger, including reading fiction, economics, computer science, robotics and debating. I didn't know what I wanted to do with my career, so I explored all these different interests through high school. It wasn't until my second year of college that I decided I wanted to be a cognitive scientist.

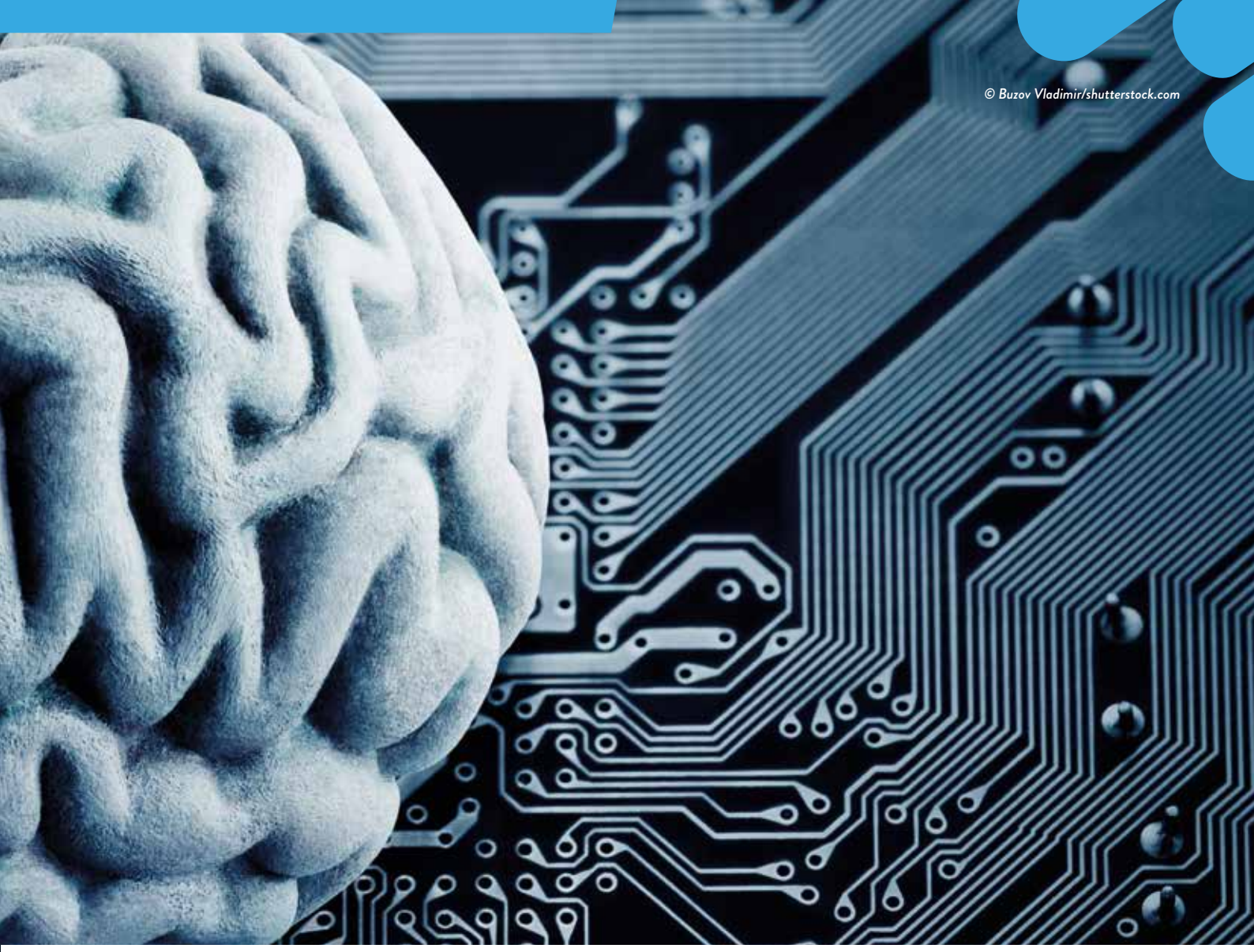
I work on understanding how memory can be used in abstract problem solving. I am particularly interested in how humans can learn so quickly from such little data – something that is currently very challenging for AI. I've discovered that we can take advantage of the relationships between concepts we've already learnt, which helps us learn new skills quickly, but current AI is less able to make connections between its past experiences.

I enjoy uncovering the 'algorithms' humans use to learn and make decisions. It was originally thought that humans struggle to multitask because our mental capacity is limited, but recent research hypothesises that it is the flexible nature of cognition that limits our ability to do multiple things at the same time. The human brain is good at reusing algorithms for different purposes. However, this causes issues if we try to simultaneously do different activities that use the same algorithms. I think this theory is interesting as it connects common experiences (such as the inability to drive safely while texting) to underlying principles.

In my free time, I enjoy rock climbing and cooking. As a graduate student, my mind is very busy when I'm working, so these activities help me clear my mind and relax.

Tyler's *top tip*

If you want to become a scientist, don't just study science. Studying non-scientific subjects, such as English and history, has been unexpectedly useful in my scientific career. Scientific discoveries require creative and critical thinking, rather than fact memorisation, and at school, these skills were most exercised in my humanities classes.



© Buzov Vladimir/shutterstock.com

Dr Harrison Ritz

Role: Postdoctoral researcher

Field of research: Computational Cognitive Neuroscience

I've always been interested in music. I played in indie bands during high school and college, and I'm an avid music collector. Sports were also a big part of my life in high school – I ran cross country and played soccer. Academically, I've wanted to study psychology for as long as I can remember. The more I learnt about psychology, the more interested I was.

I study how we switch between thinking in different ways. For example, if you switch between conversations in different languages, what's going on in your brain during that transition? To investigate this, my team has developed a new cognitive task for measuring changes in attention that involves someone reading text while listening to someone else speaking, forcing them to switch between different tasks. By analysing people's behaviour as they completed this cognitive task, we discovered that they follow two distinct steps when switching between reading and listening. First, they decide what to think about, then they gradually switch their attention to that task. The ability to measure these steps separately is important for developing a theory of how people switch their attention.

I enjoy the excitement of finding patterns in human behaviour that help us uncover the structure of the human mind. With the right experiments, you can understand then predict how people will behave in different situations. It feels like you are doing physics or chemistry experiments, but with the brain!

I think it's incredible that we can now decode the contents of the mind. By measuring someone's brain activity, we can now reconstruct simple aspects of their thoughts. For example, imagine you are shown an X or an O, then asked to think about which shape you were looking at. By analysing images of your brain activity, scientists can tell (with high accuracy) whether you are thinking of an X or an O. It's like mind-reading!

In my free time, I enjoy jogging and hiking. Running really helps me clear my head and improves my sleep. This year I ran my first half marathon. My wife and I often go hiking on weekends; there are lots of great trails in New Jersey. I also love to watch movies. Sometimes my friends and I sneak into the Princeton lecture halls in the evening and watch movies on the big projector screens!

Harrison's *top tips*

1. There are many ways to succeed, but the best direction towards progress is to push yourself to try things that don't come naturally to you.
2. Psychology and neuroscience increasingly depend on computational modelling, so develop your quantitative skills and take classes in programming and statistics.
3. Get involved in research labs to learn what research involves and whether this is the right career path for you.

How to use our education and career resources

You will find a great range of free, inspiring research articles at **futurumcareers.com/articles**

Learn key terminology relating to the field

Meet the people behind the research

Read about fascinating research projects that are happening right now

Explore fields of research, and learn about future career opportunities

Consider different educational options

Find out how the researchers got to be where they are today

Read advice from inspiring people

Many of our articles are accompanied by an animation, PowerPoint and/or podcast:
futurumcareers.com/education-resources

POWERPOINTS
Our career PowerPoints summarise research projects, highlight researchers' careers guidance and prompt you to reflect on your own skills:
futurumcareers.com/ppts

ANIMATIONS
Our animations bring the research project to life and include a downloadable script with suggested activities:
futurumcareers.com/animations

PODCASTS
Listen to researchers recount their own experiences and career pathways, and be inspired!
futurumcareers.com/stem-shape-podcasts

ACTIVITY SHEETS
Check your understanding, develop your knowledge, think critically, evaluate and continue your learning:
futurumcarees.com/activity-sheets

Keep in touch.

Thanks for reading Futurum. Did you know that all our articles and accompanying activity sheets, PowerPoints and animations are available online?

Visit our website: **www.futurumcareers.com**

We regularly publish new articles, activity sheets, PowerPoints and animations. Keep up to date by signing up to our monthly newsletter: **www.futurumcareers.com/sign-up**

Contact the researchers in the articles

Go to futurumcareers.com/articles

Select the article and scroll to the bottom

Type your question in the comments field

Click 'Notify me of follow-up comments via email'

Click 'Submit Comment'

Follow us

for updates on new instant articles, blogs and events:

Tell us what you think

We would LOVE to hear from you: send us a message through social media, comment on our articles or blogs, or send us an email: **info@futurumcareers.com**

futurum
Inspiring the next generation

The work presented in this document has received funding from the European Union's H2020 research and innovation programme – project Scientix 4 (Grant agreement N. 101000063), coordinated by European Schoolnet (EUN). The content of the document is the sole responsibility of the organizer and it does not represent the opinion of the European Commission (EC), and the EC is not responsible for any use that might be made of information contained.