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**Youth
Employment UK**

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Youth Employment UK

Helping young people thrive in
the world of work

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ISSUE 39

Championing young people through careers education

WELCOME

“Our aim is to champion young people by sharing their voices,” says Baz Ramaiah, Director of Policy and Research at Youth Employment UK (p 4). In this issue, Baz shares the results of the organisation’s Youth Voice Census, which captures young people’s experiences of and attitudes towards education and employment. “Careers education, work experience and employer engagement are the bridges into work, but each is in decline,” he says. Young people are crying out to learn more about real-world careers and how to get started on their chosen career pathway, but too often, the opportunities aren’t available.

Here at Futurum, we’re aiming to bridge that gap by providing students with access to professionals and industry leaders. You’ll find this issue is packed full of careers information and advice from experts in different fields. Discover the range of career opportunities available in radiation oncology (p 28) and marine biomedical science (p 8). Read advice about how to get started on a career in medical imaging (p 36) or soil ecology (p 16). And learn what a day in the life of a mathematician (p 52) or software engineer (p 48) really looks like.

There is a whole world of exciting careers out there, and this issue gives you the chance to explore it. As you read these pages, our contributors and collaborators will guide you down the paths they took, showing you the routes to success. Keep your eyes peeled – the spark of inspiration could be hiding just around the corner!

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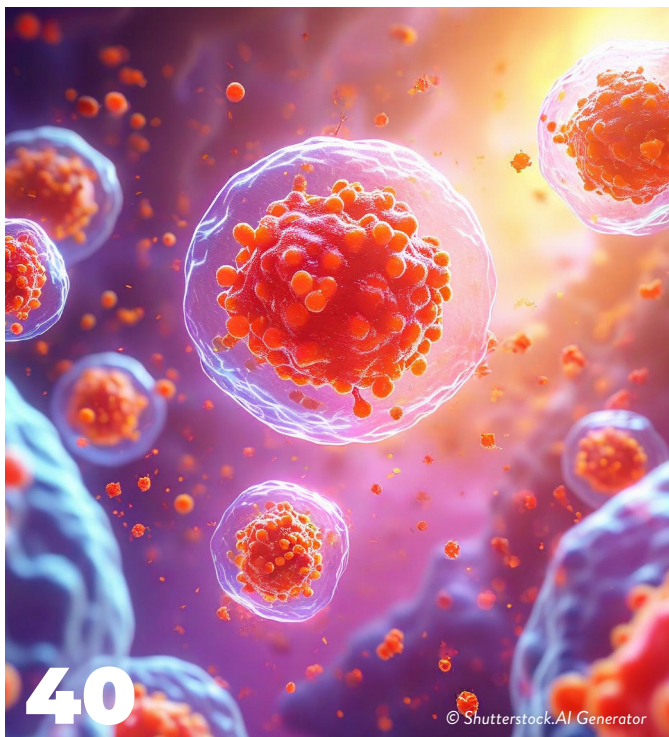
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“Our aim is to champion young people by sharing their voices.”

Baz Ramaiah, Director of Policy and Research at Youth Employment UK, tells us how the organisation is supporting young people to thrive in the world of work.



COVER STORY

Youth Employment UK

04



Our aim is to champion young people

YOUTH EMPLOYMENT UK

In the current uncertain economic climate, many young people are struggling to find employment. **Baz Ramaiah**, Director of Policy and Research at **Youth Employment UK**, tells us about the challenges young people are facing and the support the organisation is providing to ensure all young people can access and thrive in the world of work.

What is Youth Employment UK's mission?

Youth Employment UK is the UK's national body for youth employment. Our social mission is to ensure all young people, no matter their background, can access and thrive in the world of work. This also means ensuring they have access to the necessary education and training to prepare them for employment.

How do you achieve your mission?

We work with young people, employers and the government to understand what barriers young people face and develop solutions to overcome them. For young

people, we provide a wealth of resources and support to help them identify and access training and employment opportunities. We work with employers to help them become more youth-friendly – both in terms of how they create employment and training opportunities for young people, and then how they support young people once they are in work. We also do a lot of research and policy work, which I lead. We conduct research by surveying young people and employers and analysing government policies. A key part of this research comes through our annual Youth Voice Census. The aim is to provide the evidence to advocate for system-wide policy change,

ensuring that future policies have young people at their heart.

What is the Youth Voice Census?

Our **Youth Voice Census** is the largest annual survey of young people in the country. It captures their experiences of and attitudes towards education and employment. We also ask their opinions about their local area, as this has a massive influence in shaping the education and employment opportunities they have access to.

In 2025, over 9000 young people aged 11 to 30 responded to the Youth Voice Census. They came from diverse backgrounds from across the UK and represented people in school, college, university, apprenticeships, employment and those not in education, employment or training (NEET).

Every year, we update the questions slightly to reflect changes in society and government policy. For example, in the 2026 census we have included more questions about young people's experiences of technology and AI and their concerns about the cost of living. We use the huge volume of data we generate



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from the census to amplify young people's voices in policy conversations.

Why is work experience so important for young people?

In the 2025 census, over 50% of young people reported that their main barrier to getting into work was a lack of work experience. And the employers we work with also highlight that a candidate's lack of experience is their main barrier to hiring young people.

Our research has shown that work experience opportunities are crucial for getting young people into employment, as well as allowing them to gain an understanding of what the world of work looks like and helping them figure out what they want to do.

However, access to work experience is shrinking. Last year, only 26% of surveyed young people in education took part in work experience. As employers feel the financial pinch, they find it harder to create capacity to take on young people for work experience. To try and address this, we support employers to make the most out of resources that will help them create work experience opportunities for young people.

Access to careers advice is also decreasing, with only 30% of secondary students receiving careers lessons and only 23% meeting employers through school. Careers education, work experience and employer engagement are the bridges into work, but

each is in decline. Students who are Black, receive free school meals or have additional needs, along with NEET young people, are consistently the least supported, leaving the young people who most need opportunity with the least access to it. ➔



The aim is to provide the evidence to advocate for system-wide policy change, ensuring that future policies have young people at their heart.





What challenges do young people face when looking for employment?

Young people from disadvantaged backgrounds are more likely to experience physical and mental health issues and are less likely to have high-quality services in their local area to provide health support, financial support or access to work.

These issues can compound in any given individual, especially in the uncertain economic climate of today. NEET young people often sit at the intersection of

complex individual factors, where family circumstances, physical and mental health issues, educational experiences, and availability of opportunities and support in their local area all create challenges to accessing work and training.

When young people are not in education, employment or training, this is usually not for a lack of trying. Many NEET people reported engaging in dozens of different routes towards finding a job in the previous 12 months, but without success. In addition to the difficult job market,

mental health adds another challenge, with 30% of NEET people reporting that anxiety is one of their biggest barriers to applying for and securing a job. For young people who experience anxiety, the process of applying for a job can make them feel more anxious. And this anxiety can increase if they apply for a job and never hear back from the company.

The current economic climate means that the number of job vacancies is down 15% compared to the same time last year, and the number of redundancies is up 10%. This means the total number of job opportunities is shrinking while the number of people looking for work is growing, leading to a more competitive job market. This also means young people with less experience are having to compete with more experienced workers who are looking for new roles.

There is a lot of economic precarity for young people at the moment, which increases their stress and anxiety about being out of work. Almost every year in the census data, one in five young people report that making ends meet is a significant concern for them. And this adds to the pressure of finding work in a competitive market.



This is why interventions and programmes such as the government's national Youth Guarantee are really important for increasing opportunities for young people and reducing competition with more experienced people in the job market, thereby making work more accessible for young people.

How has Youth Employment UK contributed to the Youth Guarantee?

We work closely with a lot of people in government, and the government has recognised that there has been a failure to incentivise employers to offer more employment and training opportunities to young people. Thanks to our work and the evidence we have provided through our research, the government has now adopted the national **Youth Guarantee** which provides funding to employers to create work experience opportunities for young people as well as youth hubs for young people to access local support and youth job programmes.

Now, our concern is to make sure the Youth Guarantee is delivered effectively in a way that builds on the evidence of impact that we have provided from our surveys and research. We will monitor the programmes over the coming years to ensure they are iteratively improved and are successful at achieving their aims.

What other policies is Youth Employment UK supporting?

We made various policy recommendations after the 2024 census, and we're delighted to see that many of them have been taken up by local and national governments and employers!

In addition to rolling out the Youth Guarantee, we want to ensure there is a sustainable funding mechanism behind it to support the employers who are providing opportunities for young people. Underneath and supporting that, we want to ensure there is a strong social safety net for young people, in terms of access to public transport, housing and mental health support, which could help to eliminate a lot of the barriers that many people face to accessing education, employment and training opportunities.

What else does Youth Employment UK do?

Our aim is to champion young people by



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“

Our aim is to champion young people by sharing their voices. Young people want to work; they just need opportunities to do so.

”

sharing their voices. Young people want to work; they just need opportunities to do so. So, we are supporting campaigns to highlight the benefits young people can bring to employers.

We have so much on our **website**! We've been working with young people and employers for years and have built up a huge range of resources, all of which are free to access. Our 'opportunity finder' is a one-stop-shop where young people

can search for training and employment opportunities in their local area. We provide free skills training courses, along with careers guides, advice about writing CVs and tips about how to manage mental health with directions for where to look for professional support. We also provide careers advice for parents and carers as well as careers lesson plans for teachers. We have so much to share with young people to support them through education and training and into employment.



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How are sea slugs helping us understand human health conditions?

Sea slugs have a simple nervous system, making them easy to study. At the National Aplysia Resource at the **University of Miami** in the US, **Professor Danielle McDonald** and her team are breeding and raising *Aplysia californica* for scientific experiments. By understanding the nervous system of these sea slugs, scientists can learn more about the human nervous system and discover new ways to treat health conditions.



Professor Danielle McDonald

Director of the National Aplysia Resource and Director of the Glassell Family Center for Marine Biomedicine, Rosenstiel School of Marine, Atmospheric and Earth Science, University of Miami, USA

Field of research

Marine biomedical science

Research project

Breeding and raising *Aplysia* for use as a model organism

Funder

US National Institutes of Health (NIH)

Website

aplysia.earth.miami.edu/index.html

doi: 10.33424/FUTURUM708

You probably think that you don't have much in common with a sea slug, and you would be correct! However, although *Aplysia californica* look nothing like humans as they crawl along the seafloor in their colourful, slug-like bodies, they are incredibly important model organisms for understanding human health and disease.

Why are *Aplysia* useful model organisms?

"*Aplysia* have a simple nervous system with large, easy-to-study nerve cells," says Professor Danielle

Talk like a ...

marine biomedical scientist

Aplysia – a type of marine mollusc, also known as a sea slug

Husbandry – the act of breeding, raising and caring for animals

Hypoxia – a condition in which the brain does not receive enough oxygen

Ischemia – a condition in which blood supply is stopped or reduced

Macroalgae – large marine plants, also known as seaweed

Metamorphose – to change into a completely different form during development

Microalgae – microscopic single-celled aquatic plants, also known as phytoplankton

Model organism – an animal that scientists study to learn more about human health

Nervous system – the body's control centre, including the brain and nerve cells

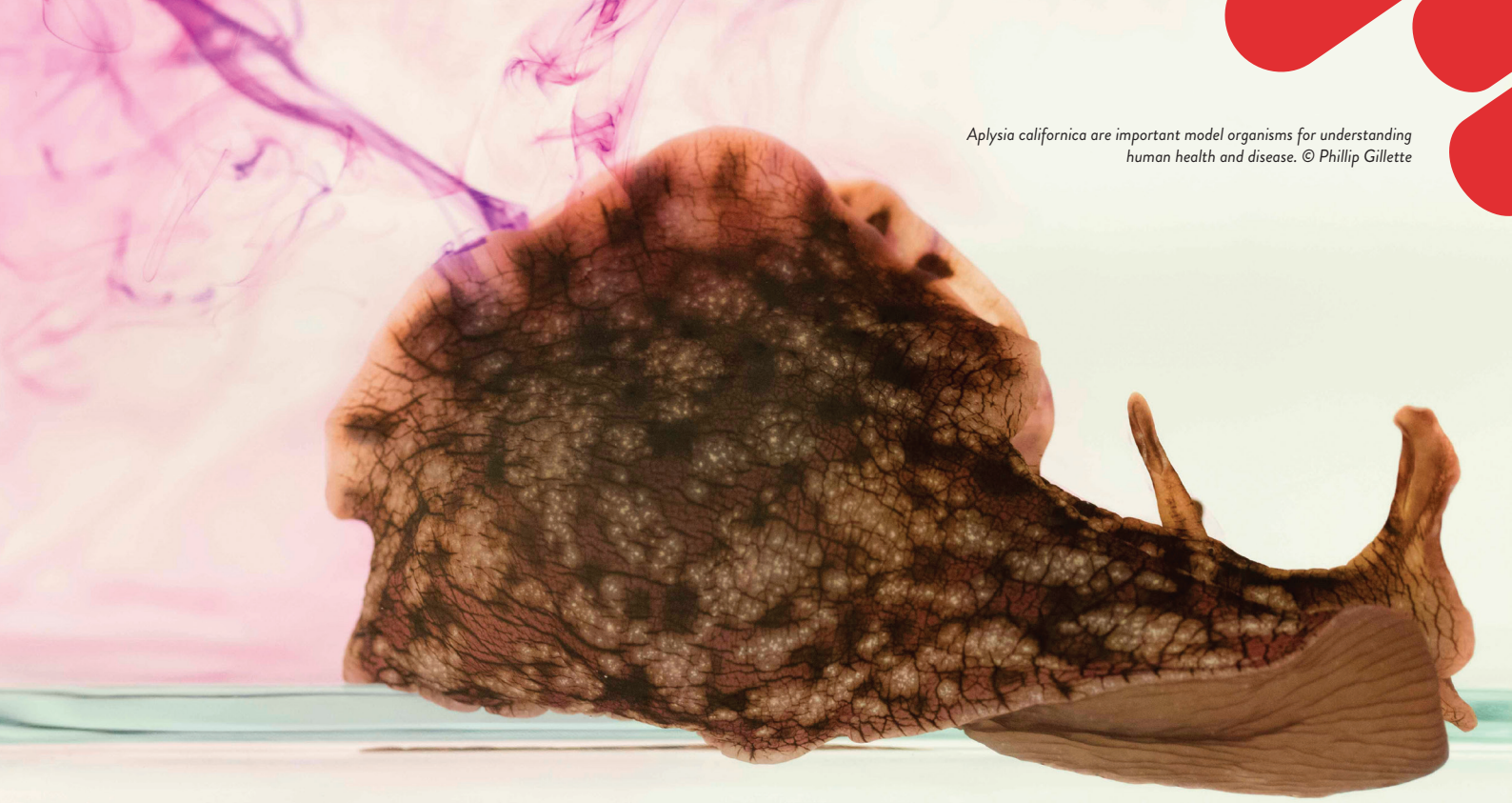
McDonald from the University of Miami. "This makes them especially useful for understanding how the brain and nervous system work. *Aplysia* also have a fairly short life span, which makes them useful for studying how the nervous system ages." Once scientists have learnt about the nervous system in *Aplysia*, they can apply this knowledge to understand more about the nervous system in humans.

Danielle is the Director of the National Aplysia Resource, the only place in the world where *Aplysia californica* are bred and raised for scientific research. Every year, the facility sends over 10,000 of these

animals to researchers around the globe for use in their experiments, providing a vital service for the scientific community.

How does Danielle's team care for *Aplysia*?

Breeding and raising *Aplysia* is not an easy task. "They have a complicated life cycle and are hard to raise," says Danielle. "They are very sensitive to water quality but produce copious amounts of faeces and mucus, and their soft tissues are easily damaged by pumps and filters." To ensure the National Aplysia Resource produces high-quality *Aplysia*, a dedicated husbandry team meticulously cares for the animals throughout their time at the facility.



Aplysia are simultaneous hermaphrodites, meaning they have both male and female reproductive organs, but they cannot fertilise themselves. Every day, the husbandry team collects thousands of fertilised eggs from each breeding pair, which are incubated until they hatch into tiny larvae. The larvae are reared in bottles kept under carefully controlled temperature, light and salinity conditions. As the animals grow and metamorphose into their adult form (weighing about 2 mg), they are moved into tanks with a continuous water flow where they are sorted by size. By the time they are six months old, *Aplysia* will have grown to 200 g, or 100,000 times their original size! They have a maximum lifespan of one year and can reach over 1 kg.

To ensure consistency, reliability and repeatability in their experiments, scientists need to know that each batch of *Aplysia* they are using has the same genetic make-up, so animals are kept in sibling groups as they develop and progress through the system, and they never share water with unrelated animals. Depending on the aims of their research projects, scientists will buy *Aplysia* of different size, age and developmental stage from the National *Aplysia* Resource, so the husbandry team carefully tracks each sibling group as it develops.

“Every week, the husbandry team changes the water in the larval *Aplysia* bottles and

monitors them with a microscope to check that they are reaching developmental milestones, such as the appearance of pink spots and digestive glands,” says Danielle. “Adult *Aplysia* require daily care such as removing faeces and uneaten food from their tanks and ensuring they have adequate water flow, and the team sterilises their tanks every week.”

As well as growing sea slugs, the National *Aplysia* Resource also grows the seaweed needed to feed them. Larval *Aplysia* eat microalgae, which is added to their bottles in careful quantities to ensure the animals have enough algae to eat but not too much that it starts growing on them. Adult *Aplysia* eat macroalgae, and are fed every Monday, Wednesday, Friday and Sunday. The facility produces over 130 kg of macroalgae every week. It is grown in large tanks which the husbandry team hand-sterilise every week, after first removing all the algae and draining 2100 gallons of water.

How are researchers using *Aplysia* to study human health conditions?

Danielle and other researchers use animals reared at the National *Aplysia* Resource to conduct research into the effects of ageing, infection, hypoxia and ischemia on the nervous system. “Hypoxia happens when the brain doesn’t get enough oxygen,” Danielle explains. “It can be caused by stroke (when the blood

supply to the brain is cut off – known as ischemia), heart or lung disease (which reduces oxygen delivery), and conditions like sleep apnoea (when you periodically stop breathing in the night).”

To study hypoxia and ischemia, Danielle and other scientists expose *Aplysia* to low-oxygen conditions or surgically manipulate them to cut off the blood supply (technically, *Aplysia* have hemolymph, not blood) to particular parts of their nervous system. They then use molecular, physiological and behavioural tools to study how the nervous system responds and to understand how the animals survive and recover. “We have found that *Aplysia* can tolerate low oxygen better than many animals, and they have protective responses that help their cells stay alive,” says Danielle. “Next, we want to figure out if there is a way to leverage the hypoxia or ischemia tolerance of *Aplysia* to benefit human health. By understanding how *Aplysia* protect their cells, we can learn new ideas about how to protect human brain cells during stroke and other injuries.”

“I hope researchers around the world use our *Aplysia* to better understand the nervous system and how it is affected by stress and ageing,” Danielle concludes. “This will help us learn more about human health conditions and develop new treatments for them.”

About *marine biomedical science*

Marine biomedical science is an interdisciplinary field that investigates how marine organisms can help us understand and treat human health conditions. For example, *Aplysia* can help us learn more about how to treat the effects of stroke in humans, which requires knowledge from marine biology, neuroscience and medicine. “An important aspect of the field is that it requires researchers from different disciplines to come together to solve problems,” says Danielle. “Connecting with researchers from different backgrounds who approach problems in different ways will open up

new pathways for exploration.”

Many important discoveries and innovations have been made thanks to research conducted on marine organisms. Scientists have used starfish larvae to understand the immune system because they are transparent and so it is possible to observe immune cells in the larvae destroying bacteria, and they have used squid to discover how nerve cells transmit signals because squid nerve cells are much larger than mammal nerve cells and so are easier to work with. Other examples of marine biomedical

research include studying coral growth to learn about bone development and healing, and studying the chemicals produced by microalgae to search for new medicines. Health technologies inspired by marine organisms include medical dressings to treat wounds and burns based on cod skin, and medicines to treat asthma and arthritis based on compounds found in mussels.

Despite all these incredible advances, the oceans still hold many secrets, so there is plenty of work for future marine biomedical scientists!

Pathway from school to *marine biomedical science*

At high school, study biology, chemistry, mathematics and computer science to learn foundational knowledge and skills for studying marine biomedical science.

At university, Danielle recommends taking courses in marine biology, comparative physiology, neurobiology, animal behaviour, genetics, molecular biology, toxicology, bioinformatics and statistics.

“If you are interested in aquaculture (breeding and raising marine animals for biomedical research), it helps to build a strong foundation in science and math early on,” says Danielle. “As your studies progress, specialise in courses such as marine biology, environmental science and veterinary science.”

Danielle recommends getting hands-on lab experience, even if it is not specifically in marine biomedical research.

“Local high school students can tour the National *Aplysia* Resource,” says Danielle. “It also offers part-time employment opportunities to University of Miami students.”

Explore careers in *marine biomedical science*

Careers in marine biomedical science generally fall into the research and aquaculture sides of the field. “You should be excited to pursue any of these careers because they can help us solve real-world health challenges,” says Danielle.

Research careers include scientists and medical doctors who study marine animals as model organisms for human health and disease, as well as environmental toxicologists who study how toxic chemicals interact with marine ecosystems. Many researchers also work as university professors, teaching the next generation of marine biomedical scientists.

Careers in aquaculture include biotechnology specialists and roles in husbandry teams caring for research animals.

The Society for Integrative and Comparative Biology (sicb.org/resources/career-information) and the American Physiological Society (physiology.org/career/teaching-learning-resources/student-resources) provide information about careers in the field of marine biomedical science.

When they are scared, adult *Aplysia* release ink as a defence mechanism, which is purple due to the colour of the macroalgae they eat. © Phillip Gillette

Download Danielle's resources from
futurumcareers.com/how-are-sea-slugs-helping-us-understand-human-health-conditions



Meet Danielle

As a teenager, I wanted to become a veterinarian. I loved animals, was interested in biology, and loved learning about the natural world.

I studied biology at university, followed by a PhD in fish physiology. Throughout my career, I have trained as a comparative physiologist, which involves studying how different species function and comparing their similarities and differences. For my PhD, I investigated kidney and gill function in different fish species. To explain my results, I had to learn about mammal physiology as well. So, even though I was studying fish, I incorporated information about humans into the interpretation of my findings, which led me to think about marine animals as model organisms.

Marine biomedical science is like solving a very complex puzzle. Studying marine animals can lead to important discoveries about human health and disease. Several Nobel Prize winners have used marine animals to answer human health questions, including Dr Eric Kandell who used *Aplysia* to study learning and memory.

Science is a collaborative effort and working with people from different backgrounds often leads to the most exciting discoveries. I enjoy working with colleagues and students to answer scientific questions by collecting data and trying to interpret our findings. It is exciting when our results support our hypotheses, and it is almost equally exciting when they don't because it means we need to do more experiments to figure out why not.

In my free time, I enjoy hiking, birding, photography, reading, and watching TV and movies, as well as being a mom!

Danielle's top tips

1. Be curious and keep asking questions.
2. Don't be afraid to make mistakes, and don't let your failures define you.

Below: *Aplysia* egg masses are collected by the husbandry team and incubated until they hatch into larvae. © Danielle McDonald



Sunflower speciation: how do new species evolve?

Have you ever wondered why some flowers look and smell so different from one another? The answer lies in the mysterious workings of evolution, the process responsible for the boundless variety of life on our planet. By studying how new species of flowers evolve, **Dr Kate Ostevik** from the **University of California Riverside** in the US hopes to improve our understanding of this process and allow us to better protect Earth's precious biodiversity.



Dr Kate Ostevik

Assistant Professor, Department of Evolution,
Ecology and Organismal Biology,
University of California Riverside, USA

Field of research

Evolutionary biology

Research project

Investigating the speciation process in
sunflowers

Funder

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2443424.

Website

osteviklab.com/home

doi: 10.33424/FUTURUM706

... Talk like an ...

evolutionary biologist

Allele – one of two or more
versions of a gene that differ in
DNA sequence

Chromosome – a thread-
like structure made of DNA
and protein that contains an
organism's genetic information

Population – a group of
organisms of the same species
that live in the same area and
interbreed

Speciation – the process
by which populations evolve to
become distinct species

Sterile – unable to produce
offspring

Structural variant – a
change to the position of a DNA
sequence or the number of times
it appears in a genome

Viable – able to survive and
develop normally

"When populations of the same species live in different environments, they face different challenges," explains Dr Kate Ostevik from the University of California Riverside. "Facing different climatic conditions, such as droughts or freezing temperatures, and interacting with different co-habitants, such as predators or pollinators, can drive the process of speciation." Over time, natural selection favours traits that help each population survive and reproduce in its own environment. "As these differences build up, the populations can become so different that they can no longer successfully reproduce with each other," explains

Kate. "When that happens, they have become separate species."

Speciation in the same place

Sometimes, the process of speciation can take place even when species live in the same habitat. In these cases, it's not geographical barriers (such as mountain ranges and rivers) that prevent gene flow between populations, but reproductive barriers. "These are incompatibilities that stop two species from mating or producing viable offspring," explains Kate. "For example, having different mating seasons or flowering at different times prevents two species from reproducing."

Why are daffodils yellow? Why do roses smell so sweet? Why are sunflowers so tall? Flowers exist in a wonderful variety of shapes, colours and smells, and it's all thanks to the process of evolution. Over immense spans of time, populations adapt to better face the challenges that life throws at them. As they do, new species emerge, adding to the incredible diversity of life on Earth.



Dune and non-dune *Helianthus petiolaris* growing in the University of California Riverside lath house.

Other species are able to mate, but their hybrid offspring may be sterile or unable to survive for very long. This is sometimes the result of structural variants: changes in the structure of chromosomes, such as sections of DNA being flipped or moved. “When these changes occur, they can reduce the successful mixing of DNA during reproduction,” explains Kate. “Even if individuals from different species mate, these chromosome differences can make offspring less likely to survive and reproduce.”

Evolving in parallel

Structural variants also play a key role in parallel evolution which happens when different populations independently evolve similar traits because they face similar challenges. Normally during reproduction, alleles (specific versions of genes) are reshuffled, meaning that advantageous alleles, can be split up. However, structural variants can help to keep important groups of alleles intact. For example, if a section of a chromosome is inverted, it can no longer pair with a normal chromosome, preventing any of the alleles at inverted genes from being reshuffled. If the inverted section of chromosome contains advantageous alleles, they can all be passed down to offspring in a single, protected unit, making it easier for the same traits and reproductive barriers to evolve repeatedly.

“Structural variants can act like shortcuts that help evolution happen in similar ways for different populations,” says Kate. Think of the structural variant as a protective container with useful tools inside. These tools are the advantageous alleles that

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If we can predict when biodiversity is generated, this might also help us predict when it will be lost.

”

help a population survive in a particular environment or overcome a particular challenge. When isolated populations use the same genetic tools to solve a similar problem, parallel evolution occurs.

Studying sunflowers

“Sunflowers are useful for studying evolution because they have adapted to similar environments, like sand dunes, in different places across the US,” says Kate. “This means we can study whether the same kind of environment is leading to the same kind of evolutionary changes over and over again.”

Previous research has shown not only that dune sunflowers regularly develop reproductive barriers with non-dune sunflowers, but that these dune sunflowers often have structural variants. “This makes us wonder if dune sunflowers in different places are independently becoming new species in the same way,” says Kate. “My team is testing this by measuring reproductive barriers within and between dune and non-dune sunflowers. We are also using greenhouse crosses and genetic analyses to understand how the genes within structural

variants help in dune environments and cause reproductive isolation.”

Kate’s research will improve our understanding of how new species form and whether that process is predictable. “This is important because if we can predict when biodiversity is generated, this might also help us predict when it will be lost,” explains Kate. “Preserving biodiversity is important because it keeps ecosystems functioning, supports human life and helps organisms adapt to a changing world.”

Learning on the job

Kate has integrated students into her research team, helping them learn and gain hands-on experience of evolutionary biology research. “Graduate students, such as Teddy Reitman, work full-time on the project and help lead different parts of the research while undergraduate research assistants, such as Yu Tian, contribute to data collection, experiments and analysis,” she says. “I also incorporate aspects of this project into a first-year undergraduate class. Students help determine which sunflowers successfully fertilised seeds by learning how to genotype both parent plants and their offspring.”

By providing these opportunities to students, Kate is training the next generation of evolutionary biologists. “Stay curious and get involved as early as you can,” she says. “Explore different interests and build connections with people who support you, because those experiences and relationships can really shape your future.”

About *evolutionary biology*

Evolutionary biology investigates the ways in which life on Earth evolves, adapts and changes over long periods of time. The field makes use of information and techniques from many other disciplines including genomics, ecology, developmental biology and palaeontology.

“Evolutionary biologists, like all scientists, try to resolve unanswered questions, which means working at the edge of knowledge,” says Kate. “Because of this, experiments do

not always work, data can be messy and we sometimes get things wrong. This is a normal and important part of science, and overcoming these challenges requires persistence, careful testing of ideas and collaboration with others.” Kate recommends developing a ‘growth mindset’ and recognising that mistakes are part of the learning process. Building a strong network of collaborators and mentors who can offer guidance, new perspectives and support will also be helpful.

“My time as an evolutionary biologist is split between analysing data, writing scientific papers and grant proposals, meeting with students to guide their research, and teaching classes,” says Kate. “There are also exciting moments when my schedule looks very different. For example, I sometimes spend a lot of time in the field collecting seeds, working in the greenhouse to grow and maintain plants, and attending conferences to share and learn about research.”

Pathway from school to *evolutionary biology*

To work in evolutionary biology, it's important to build a strong foundation in evolution, ecology and genetics, because these topics help you understand how species change and interact with their environments. “Some less obvious (but also important) courses include statistics, coding and writing,” says Kate.

“It's helpful to get involved early,” says Kate. “Try volunteering on a project, participating in community science initiatives or talking to biologists about research opportunities.”

Look for events at your local universities such as summer schools or outreach programmes. These are great ways to get experience and learn more about how to become a scientist.

Download Kate's resources from
futurumcareers.com/sunflower-speciation-how-do-new-species-evolve



Explore careers in *evolutionary biology*

Career opportunities in evolutionary biology are very broad and include research, conservation, environmental consulting, agriculture, biotechnology, science communication, education and data science.

Kate recommends exploring the resources of academic societies such as the Society for the Study of Evolution (evolutionsociety.org) to learn more about careers in the field.

Meet the team



Kate

As a teenager, I loved plants, animals and spending time outdoors, and I knew early on that I wanted to be some kind of scientist. However, I didn't fully connect

those interests until my first years of undergraduate study when I started meeting evolutionary biologists and realising I could turn my curiosity about the natural world into a career studying how species evolve and adapt.

I never find my job boring. There's always a new question to explore, and I get to do many different types of work, such as fieldwork, data analysis and teaching. I find a lot of meaning in my role as a mentor, where I help students learn, grow and develop their own paths.

I am curious, adaptable and not easily discouraged or offended, which makes it easier to take feedback and keep improving.

Kate's top tip

Be okay with making mistakes - science is all about trying things, learning and improving.



Teddy

As a teenager, I was interested in becoming a doctor. However, once I entered college, I realised that I was more interested in being outside and discovering things about the natural world than spending time in a hospital.

Science is a march towards discovery, and failure is an inherent part of the process. When we accept this fact, we can learn from failure. For instance, in my first year of working in the Ostevik Lab, I struggled to grow a cohort of sunflower seeds. Further investigation suggested that larger seeds outperformed smaller ones, and this finding led to Yu conducting a follow-up experiment that is now being prepared for publication. Even the most unexpected outcomes are worthy of further exploration.

The Covid-19 pandemic was a challenging time to be a student. Having to attend school remotely made it difficult to gain research experience. Nevertheless, I

reached out to faculty to ask if and how I could still be involved in their research. Asking people about their research is a great way to get your foot in the door, even if you have to do it over Zoom. You might gain exposure to an aspect of research that really interests you.

Teddy's top tip

Find people who have similar interests to you. Peer support is a critical part of research. These relationships can provide support in difficult times and develop into professional collaborations in the future.



Yu

I have been interested in biology since I was young. In elementary school, I received a microscope as a birthday present. I used it to observe many different things such as plant samples, insects and small organisms. That experience made me very curious about how living things work.

I didn't have very strong grades in high school, so I was worried about whether I could succeed in biology. I started college studying business, but soon felt that I needed to at least try to pursue what I truly enjoyed. So, I switched to biology and worked very hard to improve myself.

I spent my time learning biology, talking with professors and gaining research experience. Through these experiences, I became more confident in my abilities and realised that interest and persistence are more important than being perfect at the beginning.

I am very thankful for the support and encouragement I have received from my professors and other people who have

helped me. Their guidance continues to help me improve and become more confident in pursuing science.

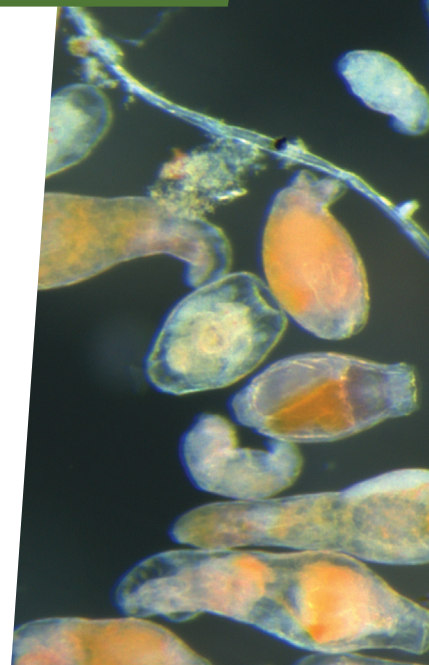
Currently, I am working on a research project investigating seed traits and the germination process in prairie sunflowers. My experiences in the Ostevik Lab have helped prepare me for a career in science.

Yu's top tip

Try to improve little by little every day, even if the changes seem small. Evolution itself works through many small changes over time. In the same way, small daily improvements can eventually make a very big difference.

Understanding the hidden world beneath our feet: building tools for studying soil organisms

Every square metre of soil is teeming with tiny organisms, such as nematodes, which play essential roles in soil stability and fertility, nutrient recycling, and pest management. However, studying these organisms can be incredibly difficult due to their tiny size and huge numbers. That is why **Dr Camila Filgueiras**, a soil ecologist at the **University of North Carolina Asheville** in the US, and her students have been developing new technologies to shine a light on this hidden world.



Dr Camila Filgueiras

Associate Professor, Biology Department,
University of North Carolina Asheville, USA

Field of research

Soil ecology

Research project

Soil ecology, biological control and new technologies for studying soil organisms

Funders

California Institute for Biodiversity; North Carolina Biotechnology Center; University of North Carolina Asheville

Websites

nemalab.org
soiltech.bio

doi: 10.33424/FUTURUM710

Talk like a ... **soil ecologist**

Arthropod – an invertebrate with a segmented body, hard external shell or exoskeleton, and jointed legs, such as an insect, spider or crustacean

Bacteria – single-celled microorganisms that live in almost every environment on Earth

Entomopathogenic nematode – a nematode that infects and kills insects

Flow cytometer – a machine that analyses cells or small organisms as they flow through a narrow stream of liquid

Machine learning – a type of artificial intelligence that learns patterns from data to identify, categorise or make predictions without needing fixed instructions

Nematode – a microscopic roundworm that lives in soil, water, plants or animals

Parasite – an organism that lives on or inside another organism and harms it

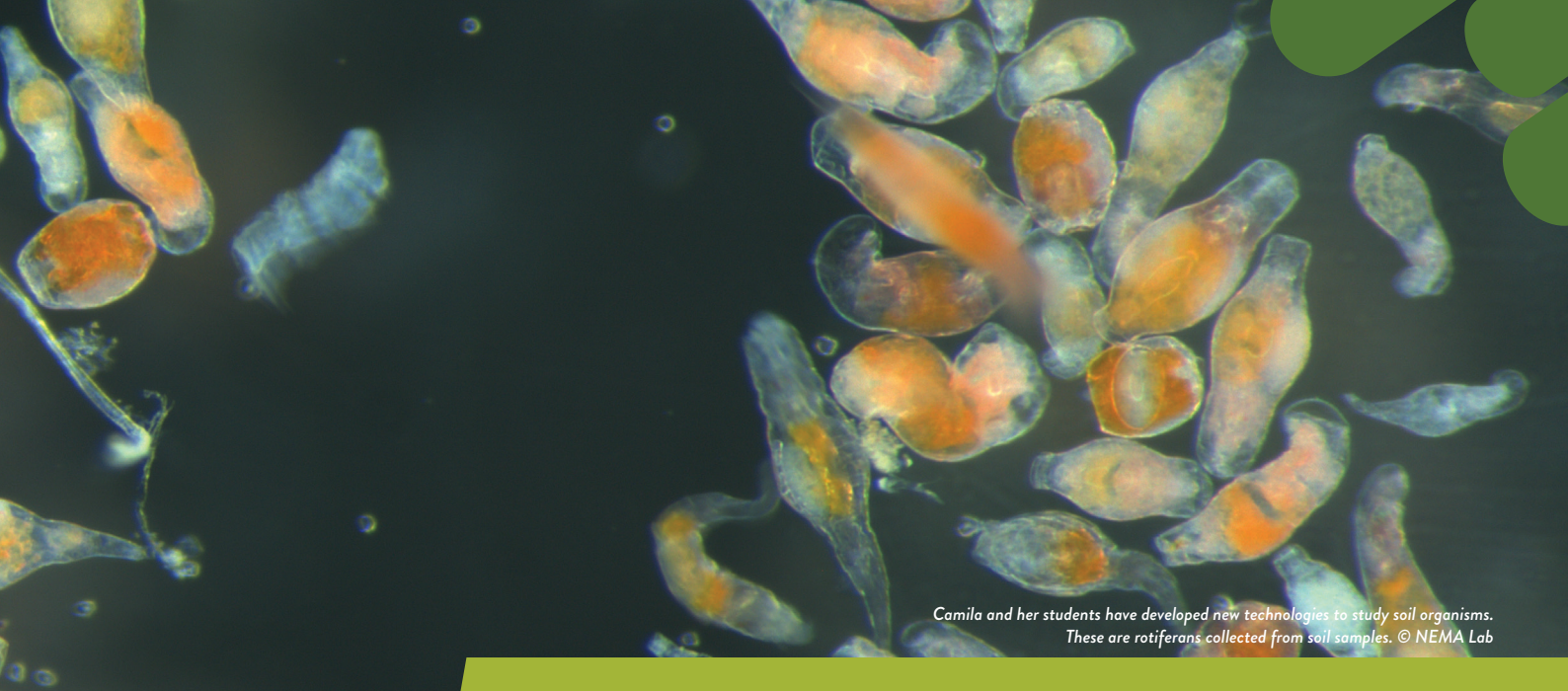
Substrate – the non-living material in a sample, such as soil, sand or organic debris

If you go digging in the dirt with a microscope in hand, you might discover nematodes – microscopic creatures that hold clues to the health of soil ecosystems. “Nematodes are tiny, worm-shaped animals that live almost everywhere on Earth – and are unbelievably abundant in soil,” says soil ecologist Dr Camila Filgueiras from the University of North Carolina Asheville. “In a single square metre of healthy

soil, it is common to find millions of nematodes living alongside hundreds of arthropods and billions of bacteria.” These nematodes help recycle nutrients, support plant growth and keep soils healthy. Some nematodes are parasites, whereas others are beneficial. Camila and her team study entomopathogenic nematodes – tiny roundworms that infect and kill insect pests, effectively acting as living, biological pesticides.

Dirt difficulties

Soil is an incredibly difficult environment to study. “Every footprint we leave covers millions of organisms that we cannot see without laborious extraction and microscopy,” says Camila. Traditional methods for studying nematodes have limitations. For example, the Baermann funnel technique collects nematodes by allowing them to move from a sample of soil



Camila and her students have developed new technologies to study soil organisms. These are rotiferans collected from soil samples. © NEMA Lab

through a mesh filter into water. However, typical recovery is only around 15%, and results change with soil type, moisture and how the funnel is built. The white trap method is used to rear nematodes from infected insects, which are collected as they emerge from their hosts. However, the Petri dishes in which these traps are set up are easily contaminated.

Soil-sampling solutions

Camila and her students have developed the NEMA Device to both extract nematodes from soil and rear more for further study, using just one piece of equipment. A soil sample is wrapped in a porous tissue inside a simple device. Nematodes swim into surrounding water and are collected after 24 hours. The same device can then be used to rear nematodes: infected insect larvae are placed inside, and newly emerging nematodes move into the surrounding water where they can be collected. Because the system remains sealed, the risk of contamination is reduced.

“The biggest challenge was designing something that was efficient and standardised but simple enough to be built and used anywhere – including in field settings or in labs with limited budgets,” says Camila. “We overcame this by deliberately working with everyday plumbing parts that are cheap, light and easy to replace, and by combining extraction and rearing into a single unit so that researchers don’t need two different set-ups.”

Trials demonstrated that the NEMA Device extracted significantly more nematodes than the Baermann funnel and was able to

produce the same number of juveniles per host as the white trap method, but with less chance of contamination. “In addition, the NEMA Device is portable, easy to take apart and clean, and inexpensive,” says Camila. “It also combines two separate workflows in a single piece of equipment.”

Counting and cataloguing the uncountable

To examine soil-dwelling organisms further, Camila and her students developed the Smart Soil Organism Detector (Smart SOD). “This is an instrument-plus-software pipeline designed to do something that has been almost impossible until now: take a soil sample and quickly extract, identify and count living soil organisms by species without killing them,” says Camila.

Smart SOD combines a custom flow cytometer and a fast, high-resolution camera. “A soil sample is diluted in water, passed through a mesh filter, and then pushed gently through a narrow flow cell,” says Camila. Lasers and a camera create a unique ‘fingerprint’ for each organism that flows through the instrument based on physical characteristics. “Living individuals are physically sorted into separate compartments with a small puff of air, so they stay alive for further study,” explains Camila. Machine learning models, trained on known organisms, can use the fingerprints and photographs to identify the organisms.

Developing Smart SOD came with its own challenges. “We had to make sense of a huge amount of multi-dimensional data, separate organisms from ‘background’ substrate, and train machine learning models on uneven

cultures,” says Camila. “We solved these problems step-by-step: tuning the flow cytometer and lasers against beads of known size, using machine learning to cleanly distinguish between substrate and nematodes, and thoroughly testing the models to make sure they worked accurately on new samples.”

Trials found that Smart SOD is fast, accurate and capable of keeping organisms alive for further study. It can distinguish between living and dead nematodes, separate nematodes from sand and soil, and identify other soil-dwellers such as mites and small insects. “Preliminary work suggests the same pipeline will work for organisms as small as fungal spores and as large as visible arthropods,” says Camila. “The long-term vision is a shared, open library of machine-learning models for soil organisms around the world, giving us a practical way to monitor global soil biodiversity.”

Simplifying soil studies

Camila has founded a start-up company, SoilTech, to scale up the technologies she and her students have invented. “Our hope is that these tools lower the barrier to working with soil life,” she concludes. The NEMA Device can help scientists collect and rear nematodes anywhere in the world and can support farmers with sustainable pest management, while Smart SOD can identify soil organisms in minutes with minimal training needed. “New tools like the NEMA Device and Smart SOD make it possible to look at thousands of individual soil organisms quickly, accurately and non-destructively,” says Camila. “Soil biodiversity is enormous and almost completely unexplored, and you are the generation that will finally get to see it!”

About *soil ecology*

“Soil is one of the most diverse yet least understood ecosystems on Earth,” says Camila. “The organisms living in just a square metre of healthy soil drive nutrient cycling, support agriculture, shape natural ecosystems and help regulate the global climate. Soil organisms also affect human health directly – they suppress plant and animal pathogens, they are a major source of antibiotics, and they underpin the biological control of pests.”

Human activities such as land-use change, pollution and intensive

agriculture are altering soil ecosystems faster than scientists can study them. Camila believes that the development of tools such as the NEMA Device and Smart SOD is essential for monitoring changes in soil ecosystems, such as how they respond to agricultural management and a changing climate.

“What I love most about this job is that every new tool we build lets us ask questions we could not answer before,” says Camila. “There is a real sense of opening a door into a previously hidden world, and doing that work alongside

students, who bring fresh ideas and energy, is the best part.”

Importantly, students can contribute to the field early in their careers. “My lab is set up so that undergraduate students are collaborators, not just observers,” explains Camila. “Students help design experiments, build soil technologies like the NEMA Device, extract and rear nematodes, and appear as co-authors on our papers. You do not have to wait until graduate school to do real science!”

Download Camila’s resources from
futurumcareers.com/building-tools-for-studying-soil-organisms



Pathway from school to *soil ecology*

“Soil ecology sits at the meeting point of several subjects,” says Camila. “Biology is the starting point – especially ecology, microbiology and invertebrate zoology. And chemistry helps you understand the soil itself, plant nutrition and how organisms interact with their environment.”

“Mathematics and statistics are surprisingly important,” says Camila. “A lot of modern soil science is about analysing patterns in big datasets. Computer science and a bit of coding make a huge difference, because tools like Smart SOD rely on machine learning and image analysis.”

“Environmental science, geology and Earth science give you the wider picture of how soils form and how they interact with climate, water and land use,” says Camila.

Explore careers in *soil ecology*

“My first piece of advice is simple – get your hands in the soil!” says Camila, “Volunteer at a local farm, community garden or natural-area restoration project. Use a hand lens or microscope to look at what is in a teaspoon of soil.”

Soil ecology is a practical, interdisciplinary field, providing a doorway to careers in research, agriculture or biotechnology.

“Organisations like the Soil Science Society of America (soils.org), the Society of Nematologists (nematologists.org) and the Global Soil Biodiversity Initiative (globalsoilbiodiversity.org) all have student-friendly resources, photo galleries and citation-quality articles online,” says Camila.

“Reach out to university labs – many soil ecologists are happy to host students for tours or summer research projects,” says Camila. “We love welcoming students to the NEMA Lab (nemalab.org)!”

As undergraduate students, **Maria Escobedo** and **Michael O'Cain** worked with Camila in the NEMA Lab.



Meet Maria

Animals and nature have fascinated me since childhood.

I would rent books from the local library and read about different ecosystems and their creatures. When I started university, Dr Filgueiras offered the opportunity to work in the NEMA Lab, which is where my passion for ecology grew. Working with insects and sharing that knowledge cultivated my enthusiasm and curiosity.

After graduation, I became a laboratory technician for SoilTech and used Smart SOD to process soil samples. I also trained Smart SOD to identify microscopic organisms and developed protocols for the proper use and maintenance of the instrument.

The NEMA Lab and SoilTech were pivotal in helping me grow. I gained friends and built connections with like-minded people who value sharing science. My confidence in public speaking greatly improved and I became less shy. And I learnt the value of insects and their importance in our world.

The NEMA Lab and SoilTech also taught me important skills such as conducting, writing about and presenting research, which helped me obtain a research assistant role in an entomology and horticulture lab in Australia, where I am now studying for a master's degree. The support, experience and skills I developed through my involvement with the NEMA Lab and SoilTech prepared me for the next steps in my career.

My favourite fact about nematodes is that plant-parasitic nematodes have a small appendage that they use to infect root-systems, like a tiny personal sword. They are like the narwhals of the soil biome!

Maria's top tips

1. Don't be afraid to ask questions or for help. Teachers and more experienced students will be happy to help you succeed, if only you ask for their support.
2. Be organised with your time and responsibilities.
3. Try something at least once before dismissing it. That group or activity could be something that interests you or helps you achieve your goals.



Meet Michael

I live in a region with an abundance of plant biodiversity and the prospect of being able to understand what I was seeing inspired me to study biology. However, I didn't start studying biology until I turned 30 – it is important to know that you shouldn't be afraid to change your mind as you move through life.

Dr Filgueiras was my zoology teacher during the time Smart SOD was being designed. Although I didn't help build it, I've since put in many hours working with the instrument, so I've become well acquainted with the technology.

I love working at SoilTech because I enjoy the exploratory nature of our lab. I also love having the opportunity to show other people the tiny wildlife we work with. Aside from providing me with employment that allows me to use the skills I gained as a biology undergraduate, SoilTech has given me the opportunity to continue practising scientific research and communication.

SoilTech is currently partnering with the All Taxa Biodiversity Inventory in California to collect, scan and catalogue every single species of soil organism in the state of California! It's a massive undertaking, but amazing to see the diversity of the soil organisms.

When I started seeing how many tiny organisms can be pulled from a single spoonful of soil, I began to feel exceedingly large! It also made me think that perhaps humans should be considered 'megafauna' on a planet that seems to be predominantly inhabited by organisms less than a millimetre long.

Michael's top tips

1. Look around your community for events or programmes that align with your interests and volunteer with local organisations.
2. Life is about living, so try different things and see what feels good.

How does the human respiratory tract microbiome affect our health?

Your mouth, lungs and airways are home to billions of bacteria and other microbes that make up your respiratory tract microbiome. When it is well balanced, this community of microorganisms helps to keep you healthy and protect you from disease. **Dr Ariangela Kozik** from the **University of Michigan** in the US studies the bacteria living in our airways to learn more about them and how they influence our health. By following her curiosity and asking the right questions, she has shed light on a century-old biological paradox and transformed our understanding of the human respiratory tract microbiome.



Dr Ariangela Kozik

Assistant Professor, Department of Molecular, Cellular, and Developmental Biology; Division of Pulmonary and Critical Care Medicine, Department of Internal Medicine, University of Michigan, USA

Fields of research

Microbiology; microbiome research; bioinformatics; immunology

Research project

Investigating commensal bacteria in the human respiratory tract microbiome

Funders

US National Institutes of Health (NIH); National Institute of General Medical Sciences (NIGMS); University of Michigan Rackham Graduate School

Website

sites.lsa.umich.edu/koziklab

doi: 10.33424/FUTURUM713

You might not realise it, but trillions of microorganisms are living on your skin and inside your body. For example, your respiratory tract – your mouth, nose, airways and lungs – houses a community of microorganisms that plays a complex role

Talk like a ... microbiologist

Commensal – an organism that lives in or on a host and benefits from the relationship while the host is neither helped nor harmed

Inflammation – an immune response that helps the body heal injuries or fight infections, causing swelling and pain

Microbiome – the community of microorganisms and their genes living on and in the human body

Next-generation sequencing – a high-speed laboratory technique that allows scientists to read the genetic code of a sample

Obligate anaerobe – an organism that cannot survive or grow in oxygenated environments

Symbiont – an organism that lives in a close, long-term biological interaction with another organism of a different species

in maintaining, and sometimes endangering, your health.

“Up until recently, we thought that healthy lungs were sterile and didn’t contain any bacteria,” says Dr Ariangela Kozik from the University of Michigan. “However, thanks to advancements in next-generation sequencing, we now know that there is a vibrant and diverse microbiome throughout our airways.” This microbiome – made up of bacteria, fungi and viruses – plays an important role in training our immune system and protecting us from disease. “Evidence suggests that people who

have chronic airway diseases, such as asthma or cystic fibrosis, have different microbial communities in their airways compared to healthy people,” continues Ariangela. “We’re still figuring out how changes in the respiratory tract microbiome lead to disease and mapping out the relationships that promote our health.”

Which microorganisms does Ariangela study?

“Throughout history, microbiologists have been focused on infectious diseases,” says Ariangela. “Knowing everything that there is to know about the microorganisms that



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infect and harm us can help us treat disease.” However, only a tiny fraction of the microbial life on Earth is harmful to humans. We know far less about the microbes that are not a threat to us, even those that are living in our bodies. “I am interested in figuring out what these other bacteria are doing,” says Ariangela.

Microorganisms that are not pathogens but have long-term interactions with us are known as symbionts. “Although they might seem less interesting at first, many of these microorganisms have long-term relationships with us and our bodies,” says Ariangela. “It is important for us to understand what these microorganisms are doing in our bodies and how they might impact our health in unexpected ways.”

What is *Prevotella*?

Ariangela is particularly interested in a genus of bacteria called *Prevotella*. The first member of this genus, *Prevotella melaninogenica*, was first discovered over 100 years ago (although it was called something else at the time). It wasn’t until 1990 that *P. melaninogenica* and other bacteria like it were grouped together as *Prevotella*. This genus has been reclassified and refined as genomic sequencing techniques have improved. “*Prevotella* are commonly found in the human respiratory tract microbiome, but when I tried to find out more about their function, there wasn’t a lot of information out there, which surprised me,” says Ariangela. “So, I decided to tackle this challenge in my own research and learn more about these commensal bacteria.”

For a long time, *Prevotella* have been classified as obligate anaerobes –

organisms that cannot grow or survive in oxygenated environments. “That didn’t really make sense to me,” admits Ariangela. “If it really is an obligate anaerobe, then how can it survive in our lungs where there is always oxygen? Right off the bat, I knew that there was something interesting to be figured out.”

How did Ariangela solve the *Prevotella* problem?

Ariangela conducted experiments to test how *P. melaninogenica* coped with varying levels of oxygen exposure. “We grew cultures of *P. melaninogenica* in specialised growth chambers, each with a different oxygen concentration,” she explains. “We found that it was able not only to survive but also to grow in concentrations of up to 5% oxygen.” At 8% oxygen, *P. melaninogenica* stopped growing, but it did not die and was able to recover when returned to an environment without oxygen.

“Our results revealed a few new things,” says Ariangela. “Firstly, *Prevotella* has been misclassified and is not an obligate anaerobe, and secondly, this means it must have some really cool mechanisms for surviving in oxygenated environments.” Although we need it to live, oxygen is actually highly toxic to most cells and can damage DNA. “All organisms need a way to deal with the harmful effects of oxygen, but we don’t know what these mechanisms are in *Prevotella*,” explains Ariangela. “In my lab, we are just at the cusp of discovering these mechanisms and figuring out how *Prevotella* survives in the human respiratory tract. We are

really excited because we have so many unanswered questions that we can now try to answer.”

What questions is Ariangela asking next?

“I’m really interested in understanding how the members of the respiratory tract microbiome interact with our immune system, especially in chronic respiratory conditions where you have cycles of inflammation,” says Ariangela. “I’m also interested in the variation in how patients with chronic respiratory diseases respond to treatment.” For example, asthma can be treated by lots of different steroids and therapies, but they do not all work well for everyone. “We don’t really know what’s behind this variability yet,” says Ariangela. “Since we do know that our respiratory tract microbiomes vary from person to person, I want to find out whether differing relationships between the microbes and the immune system can influence the way a person responds to certain therapies or drugs.”

In order to answer these larger questions, Ariangela and other microbiologists need to learn more about the specific organisms, like *Prevotella*, that make up the respiratory tract microbiome and the roles they play. “It’s like being the new manager of a soccer team who knows who their players are, but doesn’t yet know each of their strengths, weaknesses and specialties,” says Ariangela. “My goal is to fill in some of these knowledge gaps so that we can step back and really understand what the organisms in our bodies are doing.”

About *microbiology*

Microbiology is the study of microorganisms, how they live and how they interact with their environments. “It is a diverse and varied field that impacts not just health and medicine but also ecology and the environment,” says Ariangela. “There are so many sub-disciplines to explore depending on where your interests and curiosity lead you.”

Ariangela has also been interested in how the concept of race has been misused in microbiome research, exacerbating discriminatory views and a misunderstanding of scientific knowledge. “In biomedical studies, we collect demographic information about participants,” she explains. “In many studies, researchers will analyse their data based on factors such as race and

ethnicity, asking questions like: Do we see differences based on race?”

This is problematic because the concept of race is based on social constructions rather than biological realities. Using social categories, such as ‘Black’, ‘White’ or ‘Asian’, to explain biological findings can lead to serious misunderstandings and undermine meaningful research. “When we rely too much on those categories to ask our questions and do our statistical tests, we’re collapsing the totality of human diversity into these very rough, imprecise terms that aren’t based on good science,” explains Ariangela. “When doing microbiome research and trying to understand biological phenomena, it is important not to make assumptions based on misguided

applications of social categories.”

During the COVID-19 pandemic, Ariangela co-founded the Black Microbiologists Association (BMA). “I was fielding a lot of questions from family and friends about the information that was available,” she says. “Because of some of the completely unethical things that have happened to various groups of people in the name of science and medicine, there is often still a lack of trust about where to get accurate, reliable information. We wanted to be a source of information for people who didn’t know who to trust.” The BMA is also a community space where microbiologists can connect with and support each other through the challenges of a career in science.

Pathway from school to *microbiology*

At school, build a strong foundation in subjects like biology, chemistry and physics. Computing skills and an understanding of statistics are also helpful.

Getting hands-on experience in a lab is a great way to learn more about the field and figure out if this career is right for you. Taking part in summer schools is a great way to do this before you go to college or university.

At university, courses in microbiology, immunology, molecular biology and biochemistry can all lead to a career in microbiology.

Explore careers in *microbiology*

If you are interested in microbiology, explore the websites of organisations such as the American Society for Microbiology (asm.org), the Microbiology Society (microbiologysociety.org) and the American Society for Virology (asv.org) where you can find blogs and articles about new research.

To find out more about BMA, visit blackinmicrobiology.org



Meet *the team*



Ariangela

When I was really young, my parents gave me a microscope. It came with empty slides and tools, so I could just go and cut pieces off stuff and look at them under the microscope. That was my first entry into microbiology and I realised that there are all these other tiny organisms that you can't normally see but are still an important part of our world. I thought that was the coolest thing ever.

I love being able to ask questions at the edge of our knowledge. It's such an amazing feeling when you and your team discover something new and you're the only people in the world who know it. That doesn't happen all the time, but when it does, it gives me the energy to keep asking questions.

I love working with my students. They are bright, brilliant people who are going to do really cool things and change the world. I love having the privilege of training and mentoring them to become excellent scientists and follow their curiosity.

Curiosity is important, but you also have to be a good advocate for yourself. It's easy to get lost in large courses and on new campuses, but it's important to have confidence in yourself. Make the effort to talk to your professors and learn from

them. Having good mentors and role models is key.

I'm a scientist, but also a musician. Science is often seen as the opposite of art, but I think leaning into creativity is important. I love listening to and playing music, painting, and listening to birds to ground myself.

Ariangela's top tip

Don't be intimidated by your perception of where you think a scientist needs to come from or what they have to do or be. So many of my students came from artistic backgrounds, and science needs that creativity and spark!



Kelyah Spurgeon

PhD candidate, Kozik Lab

Science is about finding your passion, asking questions and getting creative! In the Kozik lab, half my time is spent at the computer using programming to predict how bacteria will behave. The other half is spent in the lab conducting experiments to test if my predictions are correct in real life. My research aims to answer an important question about host-microbe interactions: are *Prevotella* friends or foes?

I've always wanted to understand how things work. Growing up, I took things apart to look at all the parts, then put them back together. My first real glimpse into the microscopic world happened when I was in high school. I was observing the arrangement of plant cells and noticed a striking resemblance between them and ordinary brick walls. Seeing the similarities between the invisible world of microbes and our day-to-day lives motivated me to pursue a career in science.



Claire Albright

PhD candidate, Kozik Lab

Funder: Claire was supported by the University of Michigan Predoctoral Training in Genetics Program (T32GM149391).

Scientific discovery rarely happens on the first try. In the Kozik lab, I discovered the significant aerotolerance of the lung bacteria *P. melaninogenica*. However, there were many rounds of failed experiments before I got the data I needed! I had to troubleshoot, adapt my methods and try again. This trial and error is a perfectly normal part of science, making resilience an essential skill. When you finally get that breakthrough, and you have discovered something entirely new, there is no better feeling.

ADHD is my scientific superpower. Growing up, I wasn't the best student in

biology class. I was a curious kid with a love for nature, but I struggled with tests and paying attention. I didn't know if I could succeed as a scientist, but I decided to try anyway. Now I know that the traits that make me different – like my ability to hyperfixate on things that interest me and think outside the box – are the same traits that make me a great scientist. Never discount the things that make you different; they could open new doors!

How do our brains perceive the world around us?

For a long time, neuroscientists thought of the brain as a passive receiver of sensory information, waiting patiently to receive input from our eyes, ears and other sensory organs. However, predictive coding theory flips this idea on its head and proposes that our brains actively make predictions about the world around us, only using sensory information to correct their mistakes. **Dr Andrea Alamia** at the **Centre national de la recherche scientifique** in France is investigating this theory and exploring its impacts on other areas of science.



Dr Andrea Alamia

Researcher, The Brain and Cognition Research Centre (CerCo), Centre national de la recherche scientifique (CNRS), France

Field of research

Computational neuroscience

Research project

Investigating how alpha travelling waves in our brains affect our perception

Funder

European Research Council (ERC; Grant agreement No. 101075930)

Website

artipago.github.io

doi: 10.33424/FUTURUM717

Picture the scene: the lunch bell rings after a long morning of complicated algebra and dense poetry. After racing to the canteen, you rip your cheese sandwich out of its wrapper, chomp down and begin to chew... Eugh! You spit the sandwich out in disgust and stare at it in bemusement, slowly realising that you accidentally packed your brother's egg mayonnaise sandwich in your lunchbox this morning. While your friends may laugh at your misfortune, this unexpected situation can actually reveal a lot about how our brains work.

Predictive coding

"According to predictive coding theory, our brains

Talk like a ...

computational neuroscientist

Alpha-band oscillations

– rhythmic electrical pulses in the brain that help regulate the processing of sensory information

Autism –

a neurodevelopmental difference that affects how a person perceives the world

Electroencephalogram (EEG) –

a non-invasive test that records brain activity through small metal discs attached to the scalp

Predictive coding –

a theory proposing that the brain constantly generates predictions about the world, rather than passively waiting for sensory input

Schizophrenia –

a severe mental illness that causes a person to feel disconnected from reality, sometimes resulting in hallucinations or delusions

Travelling waves –

repeated patterns of neural activity that spread across the brain

are constantly generating predictions about incoming sensory information based on previous experiences and comparing these predictions with the actual sensory information we receive," explains Dr Andrea Alamia from the Centre national de la recherche scientifique. If the incoming sensory input matches the prediction, our brain suppresses it to save energy. However, if there is a prediction error (such as tasting egg when you expected cheese), your brain takes notice and searches for new information to update its prediction.

"In this framework, our perception emerges from an interaction

between 'top-down' predictions and 'bottom-up' sensory signals," says Andrea. This differs from traditional theories which emphasised the flow of incoming sensory information up to higher areas of the brain. "In contrast, predictive coding proposes a continuous two-way exchange between higher and lower levels of the brain," continues Andrea. "Rather than passively registering sensory input, predictive coding suggests that the brain actively suppresses or flags the sensory information we receive."

Alpha-band oscillations

So, how does your brain control which sensory inputs you pay

attention to and which you ignore? Well, the answer lies in alpha-band oscillations – rhythmic patterns of electrical brain activity that cycle at a frequency of 8 to 12 times a second. These ‘alpha rhythms’ spike when you close your eyes and relax, so for many years, scientists thought they were just the background hum of a brain that didn’t have much to do.

However, many scientists now think that alpha rhythms have a much more active role as the brain’s noise-cancelling filter that suppresses unnecessary information. For example, as you’re reading this article, your brain boosts alpha rhythms in regions that are receiving distracting sensory input, such as the auditory cortex. At the same time, it reduces alpha rhythms in your visual cortex, allowing you to focus entirely on the words you are reading.

“This is a fairly simple explanation and we are still trying to figure out the nuances, but it seems that alpha rhythms help to regulate when and where populations of neurons become excitable, making them more likely to receive and process information,” explains Andrea. “Scientists in our field are still actively debating this topic and some experiments suggest that the relationship between alpha oscillations and perception is not always straightforward. This is science in action!”

Travelling waves

Sometimes, alpha-band oscillations sweep through the brain like waves moving through water. Andrea discovered that these alpha travelling waves could be the mechanism that underlies predictive coding. “We showed that alpha travelling waves moving forwards or backwards through the brain emerge under different conditions,” he says. “These movements are consistent with the predictive coding model that describes how predictions and prediction errors would flow through the brain.”

For example, forward-travelling alpha waves move from the back of the brain, where sensory information is received, to the frontal lobe, where decision-making takes place. These forward waves represent bottom-up sensory processing and emerge when you are actively paying attention to sensory inputs. In contrast, backward-travelling alpha waves move



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from the frontal cortex to the sensory regions at the back of the brain. These waves represent the top-down predictions that your brain is making and filter out the unnecessary sensory information you are receiving.

“Our work provided a bridge between a prominent theoretical framework and observable brain dynamics,” says Andrea. “Through a computational simulation, we generated predictions about how travelling waves should change in different perceptual states, based on the theory of predictive coding.” Andrea and his team validated these predictions in experiments, measuring participants’ brain activity using an electroencephalogram (EEG), to provide concrete evidence that supports predictive coding theory.

Predictive coding in action

Since providing this evidence, Andrea has been exploring how predictive coding theory could be applied to other areas of science. For example, he is investigating whether it can be used to explain conditions such as schizophrenia and autism. “These conditions may involve atypical weighting of top-down predictions or bottom-up sensory inputs,” explains Andrea.

By comparing EEG data from schizophrenia patients to healthy control participants, Andrea found that those with schizophrenia displayed stronger backward-travelling alpha waves. This

indicates that their brains give more weight to internal predictions and heavily suppress sensory inputs, potentially leading to hallucinations and delusions that do not align with reality. On the other hand, Andrea conducted a similar study with autistic participants and found that they displayed stronger forward-travelling waves, indicating that their brains are less likely to suppress sensory information. This could explain why some people with autism experience sensory overload and extreme attention to detail.

Predictive coding principles can also be applied to computer vision, a type of artificial intelligence that can interpret and understand images and videos. “This theory offers a framework in which perception is guided by prior expectations as well as incoming sensory data,” Andrea explains. “This approach makes image recognition more robust when an image is blurry or incomplete, allowing computer vision systems to be more accurate and resilient.”

Under controlled, regulated conditions, Andrea is also studying how psychedelic drugs disrupt the balance between prediction and sensory input. “Studying these effects provides a unique opportunity to investigate the neural mechanisms underlying perception, cognition and consciousness,” he says. “Ultimately, the goal is to develop a more unified understanding of how brains generate perception and experience.”

About *computational neuroscience*

“**C**omputational neuroscience aims to answer some of the biggest questions about how the brain generates perception, thought and consciousness,” explains Andrea. “However, one of the biggest challenges in the field is that the brain is an incredibly complex system, and no single discipline provides all the tools needed to understand it.” Luckily, the field is one of the most interdisciplinary areas of science, so researchers often work together to combine knowledge from neuroscience, mathematics, programming, statistics and psychology.

Technological advances, such as artificial intelligence and brain imaging, are creating unprecedented opportunities to understand how the brain operates. “The next generation

of researchers will have access to richer datasets and more powerful computational tools than ever before,” continues Andrea. “This opens exciting possibilities for understanding brain disorders, improving AI systems and uncovering the fundamental principles of intelligence and cognition.”

A typical day in the life of a computational neuroscientist involves a mixture of data analysis, programming, reading scientific papers and thinking about how to develop computational models or new approaches. “I spend quite a bit of time analysing brain recordings to test our hypotheses and evaluate the results of our experiments,” says Andrea. “I also spend time writing code, running simulations and meeting with collaborators, which is especially

important on interdisciplinary projects.” Andrea also mentors students and discusses projects with postdocs. “These interactions generate new ideas and help us assess the progress of different projects,” he continues. “Interestingly, no two days are the same, which is one of the field’s appealing aspects!”

Students can best prepare for a career in computational neuroscience by developing strong quantitative and analytical skills – particularly in mathematics and coding – and by having a keen curiosity about biological and psychological questions. “Critical thinking, scientific communication skills and the ability to work across disciplinary boundaries are equally important,” says Andrea.

Pathway from school to *computational neuroscience*

At school, Andrea suggests studying mathematics, physics and computer science whenever possible. “At university, degrees in neuroscience, psychology, computer science, mathematics, physics, engineering or related disciplines can all provide strong foundations,” he says.

Learn programming languages such as Python and gain experience with statistics and data analysis. “These are particularly valuable and could make life easier at later stages, such as during a PhD,” says Andrea. “In my opinion, although large language models (like ChatGPT) are changing our approach to coding, learning to code is still one of the most valuable investments a student can make as it will help them think in a logical and structured manner.”

Students can also benefit from summer research projects, internships and coding workshops.

Explore careers in *computational neuroscience*

“Career opportunities include academic research, healthcare technology, artificial intelligence companies, neurotechnology, pharmaceuticals and data science,” says Andrea. “The interdisciplinary nature of the field means that graduates often have a wide range of career options.”

Online courses, conference talks and educational resources provide excellent starting points to explore different fields. For example, the British Neuroscience Association has a suite of educational resources for students of all ages: bna.org.uk/education-training/education.html

The Société des Neurosciences in France has a programme that aims to guide young neuroscientists in their careers: neurosciences.asso.fr/en/le-bureau-des-jeunes-chercheur%20b7e%20b7s



Meet Andrea

As a teenager, I was passionate about science fiction (especially Isaac Asimov's books) as well as dinosaurs and sports. I also practiced judo and breakdancing for many years! While I can't say these interests directly determined my career path, they certainly helped shape my curiosity and my attitude about the world. Sports, in particular, taught me perseverance, discipline and the importance of enjoying what you do.

Reading Asimov's books sparked a fascination with artificial intelligence and, more broadly, with understanding the human mind. That led me to become interested in psychology, cognition and neuroscience, even before I fully understood what those fields involved. Today, that curiosity and passion for understanding how the mind works remains my strongest motivation and continues to drive my research.

What I love most about being a researcher is the freedom it offers to investigate what really interests and impassions me. I have the opportunity to learn something new every day, and I enjoy the intellectual challenge of solving problems and understanding how things work. The combination of discovery, creativity and continuous learning makes the job incredibly rewarding.

It is important to maintain a sense of enjoyment and curiosity throughout your career. I was fortunate to have opportunities to move between countries for my PhD, postdoctoral training and eventually my permanent position. These experiences allowed me to explore new environments, meet inspiring people, exchange ideas and learn from different perspectives. I believe that being humble, open-minded and passionate are the key ingredients for success. Most other skills can be learned along the way.

Sport is still a big part of my life. Recently, I've been practising capoeira, a Brazilian martial art, and going to the gym with a friend. I also enjoy playing chess online, although it can become a little competitive at times! Outside of that, I love going to the cinema with my girlfriend or spending time with friends, enjoying an apéro (evening drink) along the Garonne River in Toulouse.

Andrea's top tips

1. Don't focus solely on the most prestigious universities or institutions. Instead, look for supervisors and mentors who will genuinely support your growth, value your work and encourage your passion.
2. Maintain a healthy work-life balance and keep your enthusiasm and curiosity alive throughout your journey.

Download Andrea's resources from
futurumcareers.com/how-do-our-brains-perceive-the-world-around-us



What is it like to work in a radiation oncology department?

Radiation oncology is a field of medical science that uses high-energy radiation to kill cancer cells. The field relies on collaboration between researchers and clinicians with a variety of skills and expertise. For example, the Department of Radiation Oncology at the **University of California, Los Angeles** is home to a diverse range of scientists including **Dr Erina Vlashi**, a radiation oncology researcher, **Dr Michael Xiang**, a clinical radiation oncologist, **Dr Danilo Maziero**, a medical physicist, and **Dr Fang-I Chu**, a biostatistician.



Dr Erina Vlashi

Field of research
Radiation oncology

Department of Radiation Oncology, University of California, Los Angeles, USA

Research project

Optimising radiation therapy for treating cancer

Funders

US National Institutes of Health (NIH); National Cancer Institute (NCI)

doi: 10.33424/FUTURUM711



Dr Michael Xiang

Field of research
Clinical radiation oncology

Talk like a ...

radiation oncologist

Glioblastoma – a highly-aggressive form of brain cancer

Oncology – the branch of medicine dedicated to diagnosing, treating and preventing cancer

Reactive oxygen species – highly reactive molecules containing oxygen that can damage DNA, lipids and other cellular structures



Dr Danilo Maziero

Field of research
Medical physics



Dr Fang-I Chu

Field of research
Biostatistics

Our cells are programmed to obey self-destruct orders when they become irreparably damaged, and most cells valiantly follow these orders, sacrificing themselves for the good of the body. However, cancer cells have been reprogrammed to ignore these instructions and continue to grow and divide, leading to the formation of tumours and the invasion of nearby tissue. If the cancer is not destroyed or removed, it can cause serious health

conditions and, ultimately, lead to death.

Fortunately, survival rates are improving as scientists and doctors develop new tests and treatments with reduced toxicity to normal tissue. For example, in the Department of Radiation Oncology at the University of California, Los Angeles, researchers and clinicians are working together to study cancer cells, test new treatments, design new therapeutic

PROFILES

machines and treat patients. This hub of collaboration and teamwork includes Dr Erina Vlashi, a radiation oncology researcher, Dr Michael Xiang, a clinical radiation oncologist, Dr Danilo Maziero, a medical physicist, and Dr Fang-I Chu, a biostatistician.

What is radiation therapy?

“Radiation therapy is a form of cancer treatment that uses high energy ionising radiation to eliminate the disease, cells,” explains Erina. “It does this either by damaging DNA molecules directly or by breaking water molecules down into hydrogen and oxygen. This produces reactive oxygen species which go on to damage other molecules in the cell, including DNA.”

Cancer cells are less efficient at repairing damaged DNA than healthy cells, so they can be destroyed with radiation doses that do not irreparably harm healthy cells. Even so, highly sophisticated machines are necessary to focus the radiation at tumours whilst protecting healthy tissue.

“The potential of harming healthy cells limits how much radiation we can deliver to a patient’s tumour,” says Erina. “If we deliver too high of a dose, we risk damaging healthy tissue.” The holy grail of cancer treatment is to find a therapy that kills every cancer cell without harming any normal cells. Unfortunately, for some cancers, radiation treatments are not yet at this stage, but Erina and her team are looking for new ways to make radiation therapy more effective.

“Radiation therapy is used to treat more than 60% of patients with cancer, and it can cure several types of the disease, especially if it is used early in the cancer’s growth,” says Erina. “However, some cancers, such as glioblastomas and pancreatic cancer, are resistant to the radiation doses that we can safely deliver to a patient. One of the main goals of our research is to figure out how to make these tumours more sensitive to radiation therapy so that we can eliminate them using safe doses.”

Why are some cancers resistant to radiation?

Like all cells, cancer cells need nutrients to survive. Through the process of cell metabolism, these nutrients are broken down or combined to help a cell perform its function. However, some cancer cells reprogramme their metabolism to use

nutrients for fuelling uncontrolled growth and division, allowing them to form tumours and spread. Some tumours, like glioblastomas, also use their metabolism to ‘shield’ themselves from radiation therapy.

“Glioblastoma cells can use their metabolic reactions to make antioxidants which neutralise the damaging reactive oxygen species generated by radiation therapy,” explains Erina. “This allows them to survive radiation therapy and makes them hard to control using current radiation therapy techniques.”

How does Erina study radiation resistant cancers?

By studying the metabolism of glioblastoma cells, Erina and her team hope to figure out exactly how these cells survive radiation therapy. “Once we understand their strategy, we can devise ways to interfere with it in the hope of making them less resistant to radiation therapy,” she says. “If we are successful, we can achieve much greater tumour control and even find cures for tumours that are currently hard to treat with radiation therapy.”

In the lab, Erina’s team use a variety of experimental techniques to study cancer cells. “We start by testing ‘cell lines’, which are cancer cells that have been isolated during the surgical removal of a glioblastoma and grown in a laboratory environment,” says Erina. “But killing cancer cells in a petri dish is easy; killing them inside a human body without harming healthy tissue is much harder.” This is why the team often tests their new therapies in experimental animals.

“To mimic a human tumour growing in the brain of a patient with cancer, we can

implant glioblastoma cells into the brains of experimental mice,” explains Erina. “We also have ‘small animal irradiators’ that resemble the machines used in the clinic to treat patients and are designed to deliver targeted radiation therapy to mice.”

What has Erina discovered?

“We have discovered that if we remove a particular amino acid (called serine) from the diet of mice with glioblastomas, radiation therapy becomes much more effective at slowing the tumours,” says Erina. “We are now looking into whether manipulating the immune system can further enhance this therapeutic effect.”

Erina’s team is also studying pancreatic cancer, which is difficult to treat with radiation therapy, due in part to the pancreas’ location in the body. “Pancreatic tumours tend to be very close to the normal gastrointestinal tract, which is very sensitive to radiation,” explains Erina. “So we are trying to find ways to protect the gastrointestinal tract so that we can make radiation therapy more effective for patients with pancreatic cancer.”

“Ultimately, our goal is to find new strategies to more effectively treat aggressive tumours with radiation therapy and to bring these strategies to patients with cancer,” continues Erina. “Achieving this goal is only possible because we have a variety of skills, tools and expertise within our department, and because we all work together towards a common goal – figuring out how to make radiation therapy as effective as possible in eliminating as many tumours as possible and extending the lives of patients with cancer.”



About radiation oncology

Radiation oncology is a dynamic and multi-disciplinary field. As well as researchers like Erina, the field includes clinicians (who treat patients and run clinical trials to test new treatments), medical physicists (who oversee the development and maintenance of the equipment that delivers radiation therapy) and biostatisticians (who help with the design of clinical trials, statistical analysis, and the interpretation and reporting of results).

Clinical radiation oncologists

Radiation is one of the three main pillars of cancer treatment, along with chemotherapy and surgery. Together, clinicians from each pillar will create treatment plans for each patient. “I meet patients for an initial consultation to discuss the benefits and potential risks of radiation

therapy,” says Michael. “Then, I tailor the treatment to the patient’s needs and deliver the therapy. Each step of the process requires working with and managing a diverse team.”

Medical physicists

“As a medical physicist working in radiation oncology, my role is broad and dynamic,” says Danilo. “In the clinic, I work closely with doctors to design treatment plans and make sure that radiation therapy is delivered safely. Radiation therapy relies on complex equipment, and part of my job is making sure these machines are working accurately and safely. I also check the radiation shielding of treatment rooms and test safety systems to make sure that patients, staff and families are protected.”

In addition to clinical work, medical physicists are deeply involved in

research and innovation. “We help introduce new technologies and treatment techniques into the clinic, making sure they are safe, effective and truly beneficial for patients,” explains Danilo.

Biostatisticians

“As a biostatistician, I use statistics to gain insight into questions within the field of radiation oncology by extracting, summarising and analysing data,” says Fang-I. “Through answering these questions, we can identify better treatments for patients and advance scientific knowledge.” Fang-I’s job involves providing statistical input throughout the course of a clinical trial – from the planning stage to data collection and analysis – and reporting on the results to make sure they are meaningful and easily understood.

Pathway from school to radiation oncology

To become a radiation oncology researcher, Erina recommends taking as many science classes as you can. “They are all important and teach you to think about scientific questions from different perspectives,” she says.

To become a clinician, Michael recommends studying biology, chemistry, physics and social sciences, all of which are usually required to get into medical school.

To become a medical physicist, Danilo recommends building a strong foundation in physics, mathematics, engineering and programming (specifically Python, C++ or C#).

To become a biostatistician, Fang-I recommends training in applied mathematics, statistics, statistical programming and critical thinking.

Download the team’s resources from
futurumcareers.com/what-is-it-like-to-work-in-a-radiation-oncology-department



Explore careers in radiation oncology

Seek hands-on experiences such as internships, research projects, work shadowing or volunteer opportunities. This is a great way to connect what you’ve learnt in the classroom with real careers.

Reach out and talk to people at different stages of their career journey in radiation oncology. Students at local universities, scientists in research labs and clinicians in local hospitals will all have different perspectives that can give you a realistic, well-rounded view of what your career path might look like.



Meet *Erina*

Conducting scientific research in radiation oncology, especially in collaborative projects, gives you the opportunity to make a large impact in the lives of patients with cancer. I love introducing my students to this field and guiding them to think about and help solve some of our biggest challenges.

Success in scientific research, including radiation oncology, is built from staying

curious, asking good questions and learning from many failed experiments. Curiosity will keep you coming back after all the setbacks.

Marie Curie, Nobel Prize Awardee for her studies in radioactivity, said, “Nothing in life is to be feared, it is only to be understood. Now is the time to understand more, so that we may fear less.” So, stay curious, work hard and fear less.



Meet *Michael*

As a teenager, I was deeply interested in math and science. However, during my studies, I discovered that I was more drawn to taking care of patients than laboratory-based research because of the human element and the immediacy of having a direct, positive impact on others.

Although we have guidelines to help us, every patient’s situation is unique. We often have to weigh-up different treatment options and work with patients to decide which option is best for them. Unfortunately, despite our best efforts, not all patients will have favourable

outcomes. In these moments, we still strive to provide comfort if cure is not possible. When caring for others, taking care of yourself both mentally and physically is also important, and seeing patients who are healthy and in remission is a motivation to keep doing what we do.

Learning is a lifelong process. We must remain flexible and open to new findings as science and technology advance. As a doctor, other humans have placed their livelihood and well-being in your hands, and that is an awesome and humbling responsibility.



Meet *Danilo*

As a teenager, I had many interests including skating, karate, music and computers. I encountered medical physics when my grandfather underwent radiation therapy, but didn’t consider it as a career until my final year of high school.

Using physics to help people is incredibly rewarding. Ideas that start as equations or theories can quickly turn into tools that improve patient care. Medical physics is a growing field with strong career prospects and the chance to work with inspiring people on meaningful challenges every day.

Strong communication skills are essential for this career. Being able to explain complex ideas and to listen to perspectives from other disciplines is critical for good teamwork and patient care. Progress often comes from considering the ideas of people who differ from your own background or way of thinking. Respecting and learning from others strengthens both clinical practice and research.



Meet *Fang-I*

There are so many questions in biology and medical science that are relevant to all human beings. While most of these questions may not be answered easily, statistics allows us to have a better grasp on them.

I cherish the opportunity to let my curiosity run free, the strong sense of belonging I get from working as part of a team, and being able to recognise how

my input fits into the bigger picture. It is an honour to be part of a positive force aiming to improve patient care and advance medical knowledge.

Students who are passionate about solving problems, helping others and advancing medical knowledge as part of a team will find pursuing a career as a biostatistician in radiation oncology satisfying and rewarding.

How can lifestyle exercise interventions be tailored to treat patients with heart failure?

Heart failure is a debilitating condition that can seriously reduce a person's ability to carry out everyday activities. At **Wake Forest University School of Medicine** in the US, cardiologist **Dr Anthony Peters** has designed a clinical trial to investigate how to improve exercise therapy for patients with heart failure. He is exploring whether combining exercise, behavioural coaching and peer support can help patients become more active and improve their quality of life.



Dr Anthony Peters

Assistant Professor, Department of Cardiovascular Medicine, Wake Forest University School of Medicine, USA

Field of research

Cardiology

Research project

Investigating how to create exercise interventions for patients with heart failure

Funders

Clin-STAR; Wake Forest Pepper Center; Clinical and Translational Science Institute; Cardiovascular Sciences Center; American Heart Association

doi: 10.33424/FUTURUM716

Talk like a ... cardiologist

Cardiometabolic dysfunction – a group of conditions affecting the heart and metabolism, including obesity, diabetes and high blood pressure

Cardiovascular fitness – how efficiently the heart and blood vessels supply oxygen to the body during physical activity

Cardiovascular disease – a general term for conditions that affect the heart and blood vessels

Ejection fraction – the percentage of blood the heart pumps out with each beat

Frailty – a medical condition often seen in older adults that involves reduced strength, endurance and physical resilience

Heart failure with preserved ejection fraction (HFpEF) – a type of heart failure where the heart pumps normally but is too stiff to fill properly between beats, along with changes in other organs throughout the body

Supervised exercise training – a structured exercise programme led by health professionals, often involving aerobic and strength exercises

Hearth failure affects more than six million people in the US and is one of the leading causes of hospitalisation and death among older adults. “My goal is to develop and test innovative exercise interventions for patients living with heart failure, a common and debilitating disorder,” says Dr Anthony Peters, a cardiologist at Wake Forest University School of Medicine.

It was Anthony's work treating people with heart failure as a clinical cardiologist that inspired him to conduct research into how to improve outcomes for his patients. Around half of all patients with

heart failure have a condition called heart failure with preserved ejection fraction, or HFpEF, and the number of people diagnosed with HFpEF is increasing as populations age and conditions such as obesity and diabetes become more common.

What is HFpEF?

Heart failure is a form of cardiovascular disease. Unlike some other forms of heart failure, the heart of a person with HFpEF can

still pump out a normal proportion of the blood it contains (its ejection fraction is preserved). The problem is increasingly understood to be a systemic problem (i.e., throughout the body), including that the heart muscle becomes stiff, making it harder for the heart to fill with blood between beats, along with changes in other organs throughout the body. As a result, the body receives less oxygen-rich blood, leaving patients breathless and fatigued.



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“HFpEF is a complex, multi-organ disorder with contributions from ageing, physical inactivity and cardiometabolic dysfunction,” says Anthony. “People living with HFpEF often experience swollen legs, difficulty breathing and extreme tiredness that can make everyday activities increasingly difficult.”

Why is HFpEF difficult to treat?

Although medications are available for HFpEF, relatively few of them substantially improve a patient’s ability to exercise, which is often one of the symptoms that most limits their independence and quality of life. In the absence of effective drugs, doctors often prescribe supervised exercise training for their patients with HFpEF.

“Supervised exercise training definitively improves exercise capacity in patients with HFpEF and is recommended in clinical guidelines for heart failure management,” says Anthony. Traditional supervised exercise programmes usually involve about 45 minutes of moderate-intensity aerobic exercise (e.g., walking, cycling) three times a week, sometimes combined with strength training (e.g., lifting weights, squats).

However, while supervised exercise programmes can be highly effective, they can also be difficult for patients to maintain over the long term. Attending regular exercise sessions may become challenging because of transport difficulties, competing responsibilities or a lack of ongoing support after the programme ends.

How is Anthony increasing the effectiveness of supervised exercise training?

Anthony’s research aims to overcome the

challenges many patients with heart failure face during and after supervised exercise training. To do this, he is conducting a clinical study called Blended Onsite and Offsite Structured exercise Training and coaching, or BOOST. Rather than simply asking whether exercise helps patients with HFpEF, Anthony’s study investigates how exercise programmes can be designed so that patients continue being active after the supervised sessions end.

“We are currently in the design and feasibility stages of BOOST,” says Anthony. “The pilot results will establish the safety and feasibility of group-mediated exercise interventions, supported by remote monitoring technology and behavioural change theory.” These initial findings will provide important preliminary data that Anthony will use to help him design and conduct a larger-scale clinical trial to fully investigate the impacts of exercise therapies for older patients with HFpEF. “We will test the hypothesis that novel, targeted exercise intervention approaches can produce improved clinical outcomes and more durable responses to exercise,” he says.

How does the BOOST programme work?

“The 12-week BOOST programme aims to increase aerobic activity to achieve cardiorespiratory benefit while maximising the likelihood of sustaining these behaviours long term,” explains Anthony. To achieve this, BOOST combines group educational sessions, one-to-one coaching, supervised group exercise and self-guided exercise at home. The programme encourages participants to find forms of exercise they enjoy while building supportive social connections and increasing their confidence

in exercising independently. It also aims to remove the barriers that many people face when trying to engage with exercise (e.g., lack of transportation to exercise classes) and hopes to initiate behaviour changes that result in patients embedding physical activity in their life. As the programme progresses, participants gradually transition from regular in-person sessions to exercising more independently, with continued coaching to help them sustain both their physical activity and the social connections they have built.

How is Anthony measuring the benefits of BOOST?

To understand the full impact of BOOST, Anthony and his team are examining a broad range of physical, cognitive and social outcomes to determine how the programme affects cardiovascular health and overall well-being. Participants complete tests of walking ability, cardiovascular fitness, grip strength and physical performance, alongside assessments of frailty, cognitive function, social connectedness and heart failure-related quality of life. These measurements are collected before the programme begins and again at the end of the 12-week intervention by assessors who do not know which intervention participants received, helping to ensure unbiased results.

“We hope to address key knowledge gaps in the treatment of the severe exercise intolerance experienced by the large and growing population of older patients with HFpEF,” says Anthony. Thanks to the work of cardiologists like Anthony, people with heart failure can be hopeful for a brighter future in which they can live a higher quality of life.

About *cardiology*

Cardiology is the branch of medicine that focuses on diagnosing, treating and preventing diseases of the heart and blood vessels. Cardiologists care for people with a wide range of conditions, from high blood pressure and heart rhythm disorders to heart failure and heart attacks. Many also carry out research to develop better ways of preventing and treating cardiovascular disease.

Anthony combines patient care with scientific research. “I love my work!” he enthuses. His role varies

from treating patients in hospital and running outpatient clinics, to analysing data and publishing new results. Clinical practice and research often go hand in hand, as caring for patients helps cardiologists identify important unanswered questions, while new research findings help doctors provide the most up-to-date treatments. “The best research questions arise from my clinical work – from seeing patients every day and working with clinicians dealing with particular challenges,” says Anthony. “On the flip side, our research and knowledge of recent

findings keep us on the cutting-edge of clinical care.”

As cardiovascular diseases continue to evolve and populations continue to age, cardiologists are facing new challenges. Anthony believes dealing with the growing burden of obesity and cardiometabolic disease, alongside harnessing the potential of artificial intelligence in healthcare, will be key priorities for the next generation of cardiologists.

Pathway from school to *cardiology*

“Establish a foundation in the sciences and, beyond that, pursue what brings you joy and excites you!” says Anthony. “This will lay the true foundation for a career in medicine.”

At school, biology, chemistry and physics are key subjects for anyone interested in studying medicine and understanding how the human body works. Anthony also recommends studying subjects such as business, health administration or economics, which will help you develop an understanding of how healthcare systems operate.

To become a clinical cardiologist, you will need to study medicine at college or university, followed by specialist training in cardiology.

To become a research cardiologist, you could study medicine, biomedical science or biology at college or university, followed by postgraduate research.

Explore careers in *cardiology*

Careers in cardiology include clinical roles diagnosing and treating patients with cardiovascular disease, and research roles studying and developing new treatments for these conditions. You could also choose to combine both roles, like Anthony.

Learn more about the cardiology research being conducted at Wake Forest University School of Medicine: school.wakehealth.edu/departments/cardiovascular-medicine

The American College of Cardiology provides information about cardiovascular research, training pathways, and career opportunities: acc.org

Download Anthony's resources from
futurumcareers.com/cardiology-with-dr-anthony-peters



Meet Anthony

As a teenager, I was interested in sports and science. These may have aligned through spatial reasoning and physics, and that translates to what I do today – heart failure physiology!

I was inspired to be a clinician-researcher in cardiology because I wanted to help individual patients at the bedside while also improving the care of patients with heart failure around the world through my research. I was inspired to work diligently to help others by my parents and family, who set an example for me each day and made sacrifices to enable me to pursue my dreams.

I was motivated to work with older patients with HFpEF because, as a clinician, I regularly encountered older patients with multiple co-morbidities (other health conditions in addition to their primary diagnosis), often led by heart failure. These people often suffered from severe exercise intolerance and frequent hospitalisations.

I became focused on improving the care of these patients through my clinical and research work, and I was particularly drawn to studying heart failure in older people by the challenges of working with these patients with multiple co-morbidities complicated by age-related changes.

When I'm not working, I enjoy spending time outdoors with my wife and three children, coaching soccer or trying new restaurants.



Let us know what you think of this educational and career resource. To provide input, simply scan the QR code or use this link: redcap.school.wakehealth.edu/surveys/?s=NPK347RYHCR3FNDC

Anthony's top tips

Keep an open mind and trust your experiences and instincts to guide you to a career that will be the best fit for you. And ask lots of questions along the way!

Making the invisible visible: how can positron emission tomography shine a light on the early stages of disease?

Conditions such as cardiovascular disease, Alzheimer's disease and Parkinson's disease can have devastating impacts on the lives of patients and their families. Unfortunately, they are often not diagnosed until far too late. That is why **Dr Kiran K. Solingapuram Sai** at **Wake Forest University School of Medicine** in the US is using positron emission tomography (PET) to improve early detection rates, support the development of new treatments and change patients' lives.



Dr Kiran K. Solingapuram Sai

Professor, Department of Radiology,
Wake Forest University School of Medicine,
USA

Field of research

Medical imaging

Research project

Imaging new markers for early detection
of Alzheimer's disease

Funder

US National Institutes of Health (NIH)

doi: 10.33424/FUTURUM721

Medical imaging techniques such as X-ray and magnetic resonance imaging (MRI) have revolutionised medicine, allowing us to see inside the body and identify problems such as fractures, tumours and organ abnormalities. Positron emission tomography (PET) goes one step further, enabling us to visualise the biological activity of diseases before they cause any visible structural change.

"Disease often changes how the body functions long before it changes how it looks," says Dr Kiran K. Solingapuram Sai from Wake Forest University School of Medicine. "PET is a powerful technique that allows us to see what is happening inside the body at a molecular level." PET is now a standard clinical

Talk like a ... **medical imager**

Alzheimer's disease – a progressive brain disorder causing memory loss, cognitive decline and changes in behaviour as brain cells become damaged and die

Cardiometabolic disease – a group of interconnected conditions that significantly heighten the risk of heart attacks and strokes

Cardiovascular imaging – a variety of non-invasive and minimally invasive tests, such as PET, used to capture detailed pictures of the heart and blood vessels

Diabetes – a long-term condition where the body cannot properly regulate sugar levels

Microtubules – microscopic protein structures within cells that provide support,

help maintain cell shape and transport materials throughout the cell

Neurodegeneration – the gradual loss of structure or function of nerve cells in the brain and nervous system

Parkinson's disease – a progressive neurological disorder caused by the loss of dopamine-producing brain cells

Positron emission tomography (PET) – a medical imaging technique that uses radiotracers to visualise biological activity within the body

Radiotracers – molecules labelled with a radioactive substance that is detectable by a PET scanner, allowing scientists and doctors to study specific biological processes in the body

tool used in oncology (the study of cancer), neurology, cardiology and the prevention of cardiometabolic disorders. For example, in cardiology, PET can measure blood flow to the heart muscle, detect inflammation, and assess viability of heart tissue after a heart attack.

The process is relatively simple. "A patient is injected with a tiny amount of a radioactive molecule, called a radiotracer, that travels through the bloodstream to specific areas of interest," explains Kiran. "A PET scanner captures signals from the radiotracer and converts them into



Kiran reviewing MRI sequencing with Imaging manager, Ms. Lena Moretz. © Wake Forest University

three-dimensional images, allowing us to determine where the radiotracer has accumulated in the body. The result is a detailed map of biological activity.” In other words, PET lets us see biology in action.

How are radiotracers developed?

“Radiotracers are specially designed molecules that target a specific biological process in the body,” says Kiran. “They are like ‘tracking devices’ that bind to a particular protein, receptor or metabolic pathway.”

The observation of different biological activities requires different radiotracers as a PET scan can only show the specific biological process or molecule that its radiotracer is designed to detect. For example, a radiotracer designed to measure how cells use glucose cannot be used to reveal cancer-related proteins. “Developing new radiotracers is critical because the targets we want to image keep changing,” says Kiran. “Each new radiotracer unlocks a new door.”

Kiran creates radiotracers using a long, iterative process, bringing together specialists in bioinformatics, chemistry and biology. Once a biological target is chosen, such as a protein linked to a specific disease, Kiran designs molecules that bind to it and chooses the most effective one. “After choosing molecules, we attach a radioactive label to them,” says Kiran. “We then test them in cells and animal models to confirm they are reaching the target and staying there long enough to image. If the results are promising, we move towards testing them in monkeys followed by human trials.”

PET and neurodegenerative disease

PET plays a vital role in the detection and

treatment of neurological disorders, such as Alzheimer’s disease, Parkinson’s disease and stroke. “These diseases begin at the molecular level long before symptoms appear,” says Kiran. “If we can design tracers that detect these early changes, we can diagnose diseases earlier and track treatment responses more accurately.”

“Neurodegeneration is a slow, devastating process, and for too long we have been diagnosing diseases only after significant damage has already occurred,” continues Kiran. “But now we can image important proteins of Alzheimer’s disease, detect dopamine deficits in Parkinson’s disease and assess brain metabolism after stroke or traumatic injury.”

An early feature of both Alzheimer’s disease and Parkinson’s disease is the degradation of microtubules – hollow structures that maintain the shape of cells, transport nutrients and support communication between cells. “Our lab developed the first PET radiotracer that can enter the brain and track microtubule integrity in living animals and humans,” says Kiran. “We are investigating additional applications for it in Alzheimer’s patients.”

Kiran and his team have also developed a PET radiotracer for a receptor that is disrupted during Alzheimer’s disease. “Being able to image this receptor gives us an entirely new way to understand neurological disorders and allows us to test whether new drugs that target this receptor are working,” says Kiran.

PET and cardiometabolic diseases

Kiran is also developing new ways for PET to contribute to the treatment of chronic

cardiometabolic diseases such as diabetes, which can lead to heart disease. “Type 2 diabetes damages blood vessels and the heart over time, which can lead to heart failure in diabetic patients,” says Kiran. “With PET, we can detect inflammatory processes developing in blood vessels and organs like the lungs and joints, often before conventional tests would raise any alarm.”

Kiran has developed a new radiotracer for a receptor that is found in the pancreas, gut and liver and is important in the regulation of blood glucose and insulin release, called GPR119. “Pharmaceutical companies have been actively trying to develop drugs that reach and activate this receptor to treat diabetes,” says Kiran. “Our radiotracer allows us to directly evaluate how the activity of this receptor changes with diabetic conditions and, more importantly, how well potential drugs engage with it.”

Imaging impact

Ultimately, Kiran’s goal is to improve patients’ lives by finding new ways to detect diseases at earlier stages and by helping doctors choose treatments that are tailored to each individual. “If we can detect Alzheimer’s disease five or ten years before symptoms appear, that changes everything for patients and families,” explains Kiran. The same principle applies to diseases such as Parkinson’s, diabetes and cancer, where earlier detection can lead to better outcomes. “The work we are doing is opening up entirely new biological windows,” continues Kiran. “We are developing new radiotracers for neurological diseases, such as Alzheimer’s disease and alcohol use disorder, and for cardiovascular diseases. We are developing new molecular imaging tools to make the invisible visible.”

About *medical imaging*

Medical imaging allows us to see inside the body, helping doctors diagnose disease, monitor treatment and understand how our bodies work. As an area of medicine, it offers a huge range of opportunities, from developing new radiotracers and treatments to improving the sensitivity of scanners and building innovative AI tools to support the interpretation of images.

“What makes this field exciting is that it sits at the intersection of chemistry, physics, biology, medicine, engineering and technology,” says Kiran. “No matter where your strengths lie, whether you love working with patients, writing code,

managing teams or discovering new science, there is a meaningful place for you here.”

The main challenge for Kiran is the length of time it takes to get new radiotracers from the laboratory to the patients. “You can develop a beautiful molecule that works perfectly in rodents and then spend years navigating the regulatory and manufacturing hurdles required to use it in humans,” explains Kiran. “Science often moves faster than the systems built to verify and translate it. That tension between scientific possibility and practical translation is the challenge I grapple with most.”

However, the reward of seeing a new radiotracer work for the first time makes it all worthwhile. “After months or years of chemistry and preclinical testing, that moment is electrifying,” says Kiran. “There is nothing quite like seeing science work. But the deepest reward is knowing that this work is helping patients. When I think about the patients and families affected by chronic disorders such as cardiometabolic diseases and Alzheimer’s disease, I think about what earlier, more accurate diagnosis could mean for them. That is what keeps pushing me every day – I am contributing to making the world a better place!”

Pathway from school to *medical imaging*

Studying chemistry, biology and physics at school and beyond will build a valuable foundation. “Never lose sight of biology,” says Kiran. “Understanding how the body works and how disease begins at the cellular level – that’s what gives the science its purpose. The best people I’ve worked with are the ones who can think like a chemist and a biologist at the same time. You need both.”

“At university, chemistry, biochemistry, pharmacology, biomedical engineering and physics are all great pathways into the field,” says Kiran. “I’d also strongly encourage students to explore computer science or data science. AI is changing how we read and interpret imaging data, and that’s only going to grow.”

“Medical imaging is not a single discipline; it’s chemistry, physics, biology and data all talking to each other,” says Kiran. “The more ‘languages’ you speak, the further you’ll go.”

Explore careers in *medical imaging*

“My first advice is simple: find a lab and get involved,” says Kiran. “Reading about science is one thing – doing it is something else entirely. The moment you pipette your first compound, run your first scan or see a PET image light up a region of the brain, something clicks. That experience is irreplaceable.”

“In my lab at Wake Forest, we actively welcome motivated high school students and undergraduates for summer volunteering,” says Kiran. “Students get to work alongside our team on real neuroscience. Some students who began with us as summer volunteers have gone on to medical schools and graduate programmes at some of the country’s finest institutions.”

“The Society of Nuclear Medicine and Molecular Imaging (snmmi.org) and the World Molecular Imaging Society (wmis.org) are the leading professional organisations in our field,” says Kiran. “They offer educational resources and host annual meetings bringing together researchers, clinicians, and students worldwide.”



Meet Kiran

I grew up in India in a lower middle-class family. Every step of the way, I depended on the generosity of people around me — family, friends, neighbours, teachers, community programmes and strangers who believed in a kid they barely knew. It taught me that where you start does not determine where you finish, and that nobody gets anywhere alone.

I lost my grandmother to dementia when she was only 64. It came on fast and it was devastating — we lost her within two months of her diagnosis. Through all of it, there were no tools to catch it early, no way to see what was happening inside her brain and, where we lived in India, no real access to specialised care even if those tools had existed. That experience never left me. Every PET tracer we develop, every image we generate, every earlier detection we inch toward — it is for her. It is for every family sitting where my family sat, watching someone they love slip away while medicine looks on without the tools to intervene.

Every radiotracer we develop starts with a biological question and then becomes an enormous, multi-layered puzzle. It takes collaboration across chemistry, biology, physics and clinical medicine to develop them. Some of the best ideas in my lab have come from conversations between a chemist and a clinician who are both looking at the same image and asking completely different questions. That collision of perspectives is where the science gets exciting.

I genuinely believe that curiosity about the world makes you a better scientist. When you sit with people whose lives look nothing like yours, you come back to the lab with a broader sense of what matters and who you are ultimately doing this work for.

Spending time with my family is what truly recharges me. My beautiful wife, Mohini, and my two cute daughters, Kiara and Kiona, have a way of pulling me completely into the present moment — and that is something no amount of data or grant writing can replicate.

Dance genuinely lights me up. I have been learning Bharatanatyam, one of the oldest and most beautiful classical dance forms from India, and it has become something I deeply treasure — the discipline, the storytelling, the way every movement carries meaning. In many ways, it reminds me of science. Both require patience, precision and a willingness to keep practising long before mastery arrives.



Download Kiran's resources from
futurumcareers.com/medical-imaging-with-dr-kiran-k-solingapuram-sai



Let us know what you think of this educational and career resource. To provide input, simply scan the QR code or use this link: redcap.school.wakehealth.edu/surveys/?s=NPK347RYHCR3FNDC

Kiran's top tips

1. Get comfortable with failure. The scientists who make the biggest contributions are the ones who have the resilience to keep going when things don't work, and the wisdom to learn something useful from every failure.
2. Find mentors who believe in you and push you. I have been fortunate throughout my career to work with scientists who challenged me to think bigger and to not be satisfied with easy answers.
3. Remember why you started. The reason for pursuing this kind of science is the impact it can have on real people's lives. On the days when experiments fail, holding on to that purpose makes all the difference.

How can we monitor disease in real time?

What if we could detect diseases before they made us ill and monitor their progression in real time? Well, at the **University of California Santa Barbara** in the US, **Dr Andrea Carlini** leads a research group that is creating chemical probes that can do just that. These structurally-responsive polymers change their shape when they interact with biomarkers of disease, opening up new possibilities for smart biomaterials and wearable sensors.



Dr Andrea S. Carlini

Assistant Professor, Department of Chemistry and Biochemistry, University of California Santa Barbara, USA

Field of research

Biomaterials

Research project

Creating structurally-responsive polymers that contain arrays of chemical probes to detect, monitor and treat disease

Funders

US National Science Foundation (NSF); Hellman Family Foundation; University of California Santa Barbara; Harold J. Plous Award

doi: 10.33424/FUTURUM723

Imagine a device that could monitor your health and tell when you're getting sick before you even start to feel unwell. With such a device, you could take proactive steps to stop the illness progressing and your doctor could monitor treatments in real time. At the University of California Santa Barbara, a research group led by Dr Andrea Carlini is creating new chemical sensors that can detect and monitor diseases. Their aim is to combine these sensors with wearable and implantable devices to improve healthcare.

... Talk like a ...

biomaterials scientist

Reactive oxygen and nitrogen species (RONS)

– highly reactive molecules containing oxygen or nitrogen that are naturally produced by the body but can be harmful when they build up

Biomarker – a measurable indicator that gives scientists information about a biological process, such as a disease or a response to treatment

Peroxynitrite – a disease-specific biomarker, which is a particularly harmful and highly reactive type of RONS that can damage DNA and proteins

Polymer – a long, chain-like molecule made from many smaller molecules

Piezoelectrics – materials that convert mechanical stress into electrical signals (and vice versa), commonly used in self-powered digital sensing devices

What are reactive oxygen and nitrogen species?

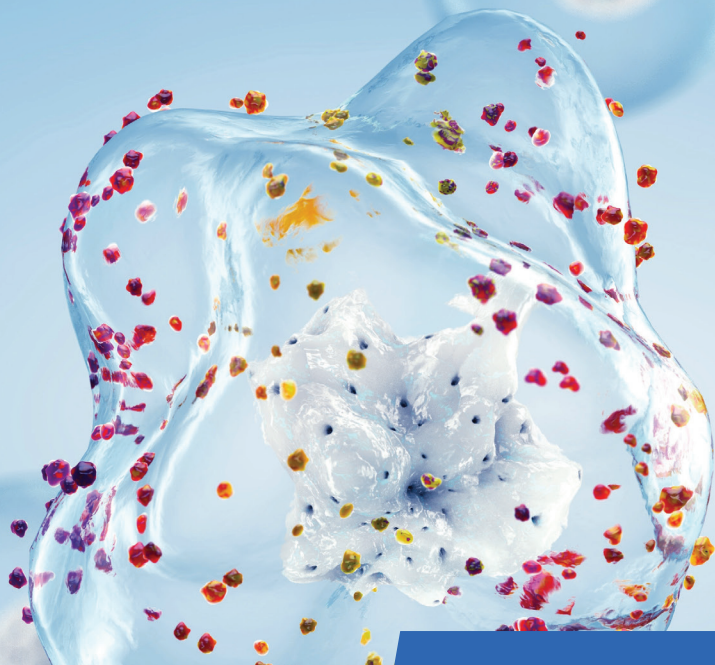
“Reactive oxygen and nitrogen species, or RONS, are highly reactive chemicals that our cells produce naturally,” explains Andrea. “In small amounts, they help cells communicate and fight infection.” However, if too many RONS are produced, they can damage proteins, fats and DNA. This is known as oxidative stress and it happens in many diseases including cancer, heart disease, injuries and brain disorders.

“My lab studies RONS because they

act like early warning signals,” says Andrea. “By measuring when and where they appear, we can track how a disease starts, progresses and responds to treatment.” Instead of only seeing the damage after it happens, Andrea and her team are creating sensors that track RONS so that they can watch how diseases progress in real-time.

What is peroxynitrite?

Peroxynitrite is a particularly harmful type of RONS made up of three oxygen atoms and one nitrogen atom. Healthy tissue produces very small amounts of it, but stressed, inflamed



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or diseased tissue produces a lot. This makes peroxynitrite a useful biomarker – something that we can measure to track a disease.

“The challenge is that peroxynitrite is short-lived, highly reactive and hard to see directly,” says Andrea. “Despite these challenges, scientists already have some useful methods for detecting it.” Some methods detect the damage peroxynitrite leaves behind, such as modified proteins, while others use fluorescent molecules that light up when they react with it. “Although these approaches are useful, most only provide a short snapshot,” says Andrea. “The traditional chemical probes used to detect peroxynitrite are small, so they are quickly consumed or cleared from the body, making it difficult to continuously track how a disease changes over time.”

What are structurally-responsive polymers?

Andrea and her team use structurally-responsive polymers covered in these chemical probes to detect and monitor peroxynitrite. The polymers are chemically modified so that their structure changes when they react with this harmful RONS. For example, like the traditional small-molecule probes, Andrea’s polymers produce an optical signal when they react with peroxynitrite, allowing the team to see where a disease is actively progressing.

But the team’s structurally-responsive polymers have one ability in particular that makes them more effective than small-molecule probes. When they react with peroxynitrite, they change shape and size, growing into larger, more durable molecules.

Because these polymer sensors are larger than small-molecule probes, they can survive in the body for much longer, allowing for continuous monitoring rather than just a single snapshot.

“Imagine a material that travels through the bloodstream as a tiny particle so it can easily reach diseased tissue,” says Andrea. “Once it arrives, it reacts with peroxynitrite, changes colour and grows into a much larger structure, like a sponge or gel, allowing it to stay in place longer.” This type of material is known as a self-reporting biomaterial because it reports on its own behaviour. As these smart biomaterials continue to react with peroxynitrite, they continue to change colour, reporting back to the scientists and doctors observing them.

But Andrea’s team are hoping to create devices that can do more than just monitor and report on disease progression. “We want to combine smart biomaterials with wearable and implantable devices so doctors can receive real-time digital information about how a patient’s body is responding to treatment,” says Andrea. “Our long-term goal is to create materials that not only detect disease, but also deliver medicine and communicate directly with healthcare technologies.” These materials would be able to provide smarter solutions to some of the most challenging problems in biomedicine that cannot be solved by passive materials.

A team effort

Designing structurally-responsive polymers is a complex process, and like all science, is not something that can be done alone. Andrea’s team contains many scientists and

researchers, all of whom contribute to the group’s goals.

“I joined Andrea’s team because I wanted to research piezoelectric polymers,” says graduate researcher Rachel Zhang. Piezoelectric polymers change shape when they are subjected to an electric field, making them flexible and ideal for creating biomedical devices. These materials can translate the biological and chemical responses of Andrea’s peroxynitrite-responsive polymers into electronic data that can reveal insights about disease progression, even when we can no longer see them. “I had never heard of piezoelectricity before I met Andrea, and I still think it’s a really neat phenomenon,” continues Rachel. “My goal is to make better flexible piezoelectric materials for biomedical uses.”

“The group’s interdisciplinary environment has allowed me to expand my research beyond traditional polymer synthesis and explore applications in wearable sensors, skin-interfacing devices and biomedical materials,” says project scientist Dr Shivshankar Mane. “The opportunity to design advanced polymeric systems with direct societal impact continues to inspire and motivate my work every day.”

“While we do study the fundamental chemistry and behaviours of biomaterials, it is all through the lens of how this can be applied to complex biochemical problems that are related to human health and well-being,” says graduate researcher Emile Morin. “This has led to collaborations with other labs which accelerate our progress on exciting projects.”

About *biomaterials*

The field of biomaterials brings together chemistry, biology, engineering and medicine to solve real healthcare problems,” says Andrea. “We can create materials that detect disease, deliver medicines, repair damaged tissues or even communicate with electronic devices.” The next generation of researchers in this field will have the opportunity to develop smart materials that continuously monitor health and provide individualised treatment. “This is a field in which you can invent technologies that directly improve people’s lives,” enthuses Andrea.

Biomaterials needs to be an interdisciplinary field because it aims to solve complex problems within the human body, which is itself a very complex thing. “A material that works perfectly in the laboratory may behave very differently inside the human body,” explains Andrea. “That’s why biomaterials scientists must be creative, patient and willing to learn from unexpected results. Every unexpected result is a clue, and learning to follow those clues is what makes you a better scientist.”

“As a biomaterials scientist, no two days are exactly the same,” continues

Andrea. “That’s one of my favourite parts about the job.” While Andrea develops new research ideas and designs experiments, her students carry out the hands-on work, from synthesising molecules and making polymers to testing new materials. “Research is driven by troubleshooting, so active troubleshooting often reshapes our plans and sends us in exciting new directions,” says Andrea. “My high school calculus teacher once told me, ‘Success is 10% smarts and 90% drive.’ That mindset has guided my career. In research, persistence and curiosity are often more important than having all the answers.”

Pathway from school to *biomaterials*

“Build a strong foundation in chemistry and biology,” says Andrea. “Take polymer chemistry and biomaterials courses whenever they’re available.”

“Don’t wait until graduate school to get involved in research,” says Andrea. She recommends joining a chemistry or materials club, looking for research opportunities at local institutions and applying for internships.

Explore careers in *biomaterials*

Andrea recommends exploring articles that interest you from the American Chemical Society ([acs.org](https://www.acs.org)), the Royal Society of Chemistry ([rsc.org](https://www.rsc.org)) and the Materials Research Society ([mrs.org](https://www.mrs.org)).

“Studying biomaterials can open doors to careers in academic research, biotechnology, pharmaceuticals, medical devices and sustainable materials, where scientists and engineers develop new technologies that improve both human health and the environment,” says Andrea.



Meet *Shivshankar*

As a teenager, I was deeply influenced by my father, who was a school teacher.

Watching his dedication to educating students inspired me to pursue a career where I could both discover new knowledge and share it with others. I developed a strong interest in science because I was always curious about how things worked and enjoyed experiments that connected classroom concepts to everyday life.

Working alongside researchers from diverse scientific backgrounds encourages creative problem-solving and accelerates the translation from fundamental science to practical applications. Andrea's lab

provides an ideal platform to pursue research that addresses real-world challenges in healthcare.

Be curious, build strong scientific fundamentals and gain research experience early. Biomaterials is a rapidly evolving and highly interdisciplinary field, so being open to learning across chemistry, biology and engineering can create many opportunities. Finally, communicate your science effectively and pursue questions that genuinely excite you, because passion and curiosity are powerful drivers of a successful scientific career.



Meet *Emile*

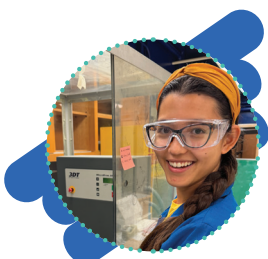
Growing up, I spent my summers working on palaeontological sites digging up fossils in Montana or wolf-watching in Yellowstone. Through these experiences, I became fascinated with the natural world and took as many STEM classes as possible in my undergraduate studies.

When I first started working with this group, it was just myself, Professor Carlini, and a group of undergraduate students. The process of starting projects from scratch and building them into successful research ideas gave me a real

understanding of how continuous hard work pays off.

Get involved in a lab as soon as possible.

Being exposed to the scientific way of thinking, regardless of the exact topic, will help build your understanding. If you approach any research with an attitude of curiosity, you'll find value in the work. Also, interdisciplinary collaboration has become essential as cutting-edge research requires expertise across several fields of study.



Meet *Rachel*

As a teenager, I wanted to be a diplomat.

That's very different from what I'm actually doing now! But one thing that has stayed the same is that I've always wanted to be of service to the world and to help people. Through my research, I get to work on solving real-world problems that will help others.

After grad school, I plan to teach as a professor. I want to help more people gain a good understanding of science and chemistry, because I believe that education is empowerment.

Research can be frustrating because the results don't always match your expectations.

It can be difficult to remember that a 'bad' result still tells us something we need to know to reach our goal. During these moments, my lab mates' encouragement and my professors' support keep me motivated.

Stay curious! Not just about the science, but also about the career possibilities out there. You don't know what you don't know, and there's so much more out there than you might realise.

How can biomass improve global sustainability and help the textile industry?

Every day, the textile industry contaminates thousands of litres of water with harmful dyes that can impact the environment, aquatic life and human health if not properly treated before being released into waterways. At the **University of the Basque Country** in Spain, chemical engineer **Dr María González Alriols** and applied chemist **Dr Mirari Antxustegi Bengoetxea** are studying how biorefinery processes can create biochar and hydrochar. But how could these charcoal-like solids help clean wastewater, and why are the researchers excited about the possibilities?



Dr María González Alriols



Dr Mirari Antxustegi Bengoetxea

Department of Chemical and Environmental Engineering, University of the Basque Country, Spain

Fields of research

Chemical engineering; environmental engineering; renewable energy engineering

Research paper

Apple Pruning-Derived Activated Biochar and Hydrochar for Efficient Dye Adsorption: Response Surface Methodology-Guided Optimization, Kinetic Analysis, and Mechanistic Modelling. Antxustegi and Gonzalez Alriols et al. (2026)

doi: [10.3390/recycling11030050](https://doi.org/10.3390/recycling11030050)

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doi: [10.33424/FUTURUM709](https://doi.org/10.33424/FUTURUM709)

Download María and Mirari’s resources from futurumcareers.com/how-can-biomass-improve-global-sustainability-and-help-the-textile-industry



Talk like a ...

chemical engineer

Adsorption – a phenomenon in which atoms, ions or molecules accumulate on a material’s internal or external surface. Unlike absorption, where a substance penetrates and disperses throughout the bulk of a material, adsorption is confined exclusively to the surface

Biochar – a carbon-rich, porous solid similar to charcoal which is created by heating biomass without oxygen at very high temperatures

Biomass – plant, animal or microorganism-based material which can be used as a source of

energy, materials and chemicals

Biorefinery – a facility that converts biomass into valuable products such as fuel and materials

Hydrochar – a carbon-rich solid created from biomass under aqueous conditions and moderate temperatures

Surface functionality – the available chemical groups on the surface of a material that directly influence its interaction with other substances, such as its capacity to selectively attract and adsorb specific compounds

As global consumption and energy demand increase, so does the need to find sustainable resources that do not harm the environment. At the University of the Basque Country, chemical engineer Dr María González Alriols and applied chemist Dr Mirari Antxustegi Bengoetxea are studying how biorefinery technologies can transform agricultural waste and by-products into valuable resources that can benefit industries and the planet.

What is a biorefinery?

Similar to an oil refinery that converts crude oil into fuel and other products,

a biorefinery aims to reach the same outcome by using biomass instead. “There are different types of biorefineries depending on the raw material they use, but they all rely on biomass – which is renewable and organic – rather than fossil fuel resources that are non-renewable (though also organic),” explains María.

Some common types of biomass that are used in biorefineries include wood and woodchips, crops grown for energy production (such as switchgrass), agricultural waste (such as the leftovers of food crops), household waste, food and garden waste, treated sewage, and animal waste. “Some

biorefineries are based on sugar-rich feedstocks (e.g., sugarcane or corn), others on oil-rich materials (such as vegetable oils or microalgae), others on woody biomass (including wood and straw) and others on the organic portion of waste streams (such as municipal solid waste, sludge or industrial residues),” explains Mirari.

Similar to classic oil refineries, biorefineries produce biofuels such as bioethanol, biodiesel and biogas (which can be used to make transportation more sustainable). Biorefineries also produce a huge range of other chemicals and materials from which many products present in our everyday life can be produced, such as bio-plastics, bio-textiles and bio-adhesives.

Why can biorefineries be environmentally positive?

Since they rely on using biomass as their source, biorefineries offer a much more sustainable option than oil refineries. “One of the most promising aspects of biorefineries is that they can make by-products and waste materials (such as agricultural and forestry residues or urban waste) more valuable,” says María. “These materials are already generated and would otherwise require treatment, so transforming them in biorefineries improves overall sustainability and resource efficiency.”

Biomass is also widely available across the world, which means it is a fuel system that many people can make the most of. “Fossil fuel resources are concentrated in specific regions of the world, making their supply highly dependent on geopolitical and market instability,” explains Mirari. “On the other hand, biomass is widely distributed and locally available, which helps reduce these risks and supports a more stable, resilient and decentralised resource system.”

What are biochar and hydrochar?

Within their research team, María, Mirari and their students María Molina Corbacho and Lucía Martín Pérez are investigating how biorefineries can turn biomass into two products: biochar and hydrochar. Biochar is obtained through a thermochemical process that uses high temperatures (500-900 °C) in an oxygen free atmosphere, while hydrochar is produced when biomass is treated with an aqueous solution under milder temperatures



María and Mirari at a conference.

(400-500 °C). “This process avoids the need for drying the biomass and efficiently converts it into a solid carbon material, making wet organic waste (such as sludge or food waste) valuable,” says María.

Thanks to their specific properties, biochar and hydrochar can be used in various processes, such as improving soil and capturing carbon from the atmosphere. They can also be used as adsorbents to remove pollutants from contaminated water, which is what the research team has been investigating.

“Biochar is increasingly valued as an adsorbent material for removing toxic compounds from water and gas streams thanks to its high porosity and surface area, while hydrochar provides a high density of surface functional groups that enhance interactions with dye molecules,” explains Mirari.

How can biochar and hydrochar help the textile industry?

According to the United Nations, the textile industry uses 93 billion cubic metres of water each year, with the creation of a single pair of jeans using 7,500 litres. This accounts

for nearly 20% of global industrial water pollution and leaves large amounts of water filled with harmful dyes that seriously affect aquatic life and water quality.

The biochar and hydrochar that María and Mirari are creating in biorefineries can remove some of these pollutants and has shown particularly high adsorption capacities for methylene blue – a common dye used in the textile industry that is environmentally harmful, toxic, carcinogenic and can even be fatal to humans in high doses.

This aspect of María and Mirari’s work is particularly interesting as the biochar and hydrochar comes from the by-products of apple orchards. Each year, orchard trees across the world are pruned and cut regularly, leading to a considerable amount of biowaste being produced in the form of leaves and branches. By turning this biomass into biochar and hydrochar, the research team can decontaminate wastewater in a biorefinery process fuelled by orchard wood scraps – a process that not only benefits the textile industry but reduces wastage within the agricultural industry as well.

“I am passionate about biorefinery processes because they enable the transformation of waste into valuable resources, promoting a more circular and efficient use of materials,” says María. Mirari continues, “Biorefinery processes also reduce our dependence on fossil fuel resources and improve resource autonomy.” By using advanced engineering and re-envisioning waste as something useful, María and Mirari’s work is helping to create a world where fuel, chemicals and materials can be produced in a more sustainable way for everyone.

María and Mirari with students María and Lucía.



How can psychologists generate more realistic avatars for virtual reality experiments?

Virtual reality is a useful tool for a range of research areas, from perception to therapeutic interventions, where avatars can be used as substitutes for real people in virtual experiments. However, while virtual reality video games often contain lifelike avatars, academic researchers do not have the technology, money or animation expertise to create avatars that look and behave like real people, which limits their usefulness. To address this problem, **Dr Rachael Taylor**, a behavioural psychologist at the **University of Kent** in the UK, has developed an accessible method for constructing realistic avatars.



Dr Rachael Taylor

School of Psychology, University of Kent, UK

Field of research

Behavioural psychology

Research paper

High-Fidelity Avatars for Behaviour and Cognition Research in Virtual Environments: An Accessible Construction Method for Scientists. Taylor, R. L., et al (in press)

Funder

Rachael Taylor's work is funded by a research grant from the Economic and Social Research Council (ESRC Grant no ES/X011208/1) to Markus Bindemann at the University of Kent and Mike Burton at the University of York.

doi: 10.33424/FUTURUM705

Have you ever worn a virtual reality headset and entered a computer-generated world to race cars, fight dragons or kill zombies? Virtual reality (also known as VR) allows players to immerse themselves in simulated environments, so they feel truly present in a game.

But virtual reality has many uses beyond entertainment. Psychologists are increasingly conducting experiments in virtual reality because it allows them to create controlled immersive environments to observe how people behave in different situations. For example, by placing

... Talk like a ...

behavioural psychologist

Avatar – a computer-generated representation of a person

Blend shape – a deformation of a 3D model

Social presence – the sense of being in the presence of another person

Social signal – a behaviour used to communicate, such as a facial expression or body language

Virtual reality – a computer-generated environment that someone can enter, usually by wearing a virtual reality headset

participants in virtual rooms with avatars, psychologists can explore how people react to social signals such as gestures and body language. And virtual reality can be used for therapy by exposing patients to immersive experiences while keeping them in a safe space.

"I use virtual reality to investigate how people interpret an avatar's social signals, such as facial expression and eye gaze," says Dr Rachael Taylor, a behavioural psychologist at the University of Kent. "Avatars have the potential to be useful research tools because they can be programmed to display consistent behaviours, allowing for standardisation between different participants during experiments."

However, it is challenging to create computer-generated avatars that

look and behave like real humans, which limits how useful these virtual experiments can be. "Previous research has shown that a person's sense of social presence towards an avatar is influenced by how well the avatar's appearance and behaviour compare to that of a real person," Rachael continues. "Therefore, creating realistic avatars that can display social signals is an important step in improving their use for future research."

How can psychologists create realistic avatars?

The research team in the School of Psychology at the University of Kent has developed a method that other psychologists can use to create more realistic avatars for their virtual reality experiments. The first step involves using a 3D scanner to take many photos of a

Download Rachael's resources from
futurumcareers.com/how-can-psychologists-generate-more-realistic-avatars-for-virtual-reality-experiments



The process of creating an avatar with realistic appearance and behaviour. © Rachael Taylor

real person's head from different angles, capturing both the shape of their face and the texture of their skin and hair. Scanning software can combine the photos to create a visually accurate digital 3D model of the person's head.

Then, having created an avatar head with a realistic appearance, the next step is to give it realistic behaviour. "To do this, you need to create eye and mouth sockets in the 3D model of the face, so you can insert moveable eyes and teeth," Rachael explains. "You also need to create blend shapes, which are deformations in the 3D model that reflect movement of different parts of the face, such as an eyebrow raise." By combining different blend shapes, psychologists can give their avatars different facial expressions. Finally, they can connect their realistic avatar head to a virtual avatar body created using free character creator software.

How realistic are Rachael's avatars?

For this avatar creation method to be useful for psychology experiments, people

need to respond to the avatars it produces in the same way as they would respond to humans. To test whether this is the case, Rachael and the team conducted their own virtual reality experiments to see how people react to the avatars' eye gaze and facial expressions.

You are more likely to process the properties of an object, such as its location or colour, if you see someone else looking at it – a phenomenon known as the gaze-cueing effect. Rachael tested whether her avatars produced the gaze-cueing effect by placing participants in a virtual room with an avatar, who would gaze towards the left or right before a white sphere appeared in the room. Participants had to identify the location of the sphere as quickly and accurately as possible. The team found that the spheres were indeed located more quickly when the avatar gazed towards (rather than away from) its location before it appeared, demonstrating human-like gaze-cueing effects.

To see how participants recognise avatar facial expressions, the avatars were also

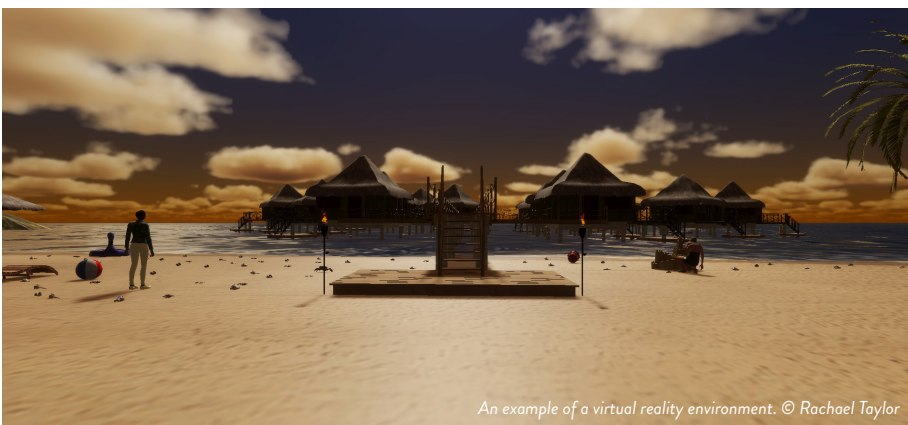
animated to display the emotions of happiness, sadness, anger, fear, surprise and disgust. When participants were placed in a virtual room with these avatars, they were generally accurate at recognising their facial expressions.

"Our findings demonstrate the validity of our avatars as research tools and show they have good potential for exploring how people process social signals in virtual reality experiments," Rachael concludes. "Our avatars produce a strong gaze-cueing effect and are also capable of displaying complex facial expressions."

How is Rachael's research helping psychologists?

"By developing our avatar construction method, our goal is to empower researchers who are inexperienced with creating avatars to be able to generate realistic avatars for their virtual reality experiments," says Rachael. This method for creating realistic avatars does not require expensive equipment, specialist software or animation expertise meaning it is accessible for all psychology researchers.

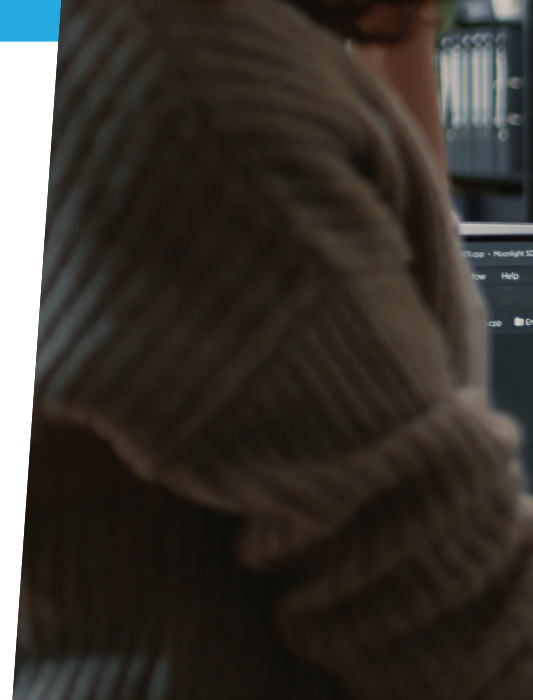
"In addition to developing the avatar construction technique, I have also written a detailed guide for researchers who are interested in using virtual reality in their experiments but don't know where to begin," says Rachael. Through this work, Rachael and the team at the University of Kent hope to advance the wider fields of psychology and behavioural science by teaching other researchers how to create immersive virtual reality experiments containing realistic avatars.



An example of a virtual reality environment. © Rachael Taylor

Can AI find and fix hidden software bugs?

Software bugs can have devastating consequences, so finding and fixing them is a constant job for software engineers. At the **University of Alberta** in Canada, **Dr Thibaud Lutellier** is investigating how AI can help software developers to improve code.



Dr Thibaud Lutellier

Department of Science, Augustana Campus,
University of Alberta, Canada

Field of research

Software engineering

Research project

Using AI to detect and fix software bugs

Funder

Natural Sciences and Engineering Research
Council of Canada (NSERC)

doi: 10.33424/FUTURUM712

Talk like a ...

software engineer

Annotation – metadata added to code that provides extra information about how it should be used or understood

Code smell – a sign that code may contain a design problem or be difficult to maintain, potentially leading to future bugs

Code refactoring – reorganising and improving the structure of code without changing how it behaves

Jupyter Notebook – an interactive document that combines computer code, text and outputs such as graphs and tables

Software bug – an error in a computer program that causes unexpected or incorrect behaviour

Software is everywhere, from mobile phones and electric cars to banks and hospitals. However, even the most carefully designed software can contain bugs – errors that cause programs to behave in unexpected ways. “A minor bug might simply cause a visual glitch, like an incorrectly positioned image on a webpage,” says Dr Thibaud Lutellier, a software engineering at the University of Alberta. “However, a major bug can have real-world consequences, such as disrupting an airport or allowing attackers to steal banking information.”

What are Jupyter Notebooks?

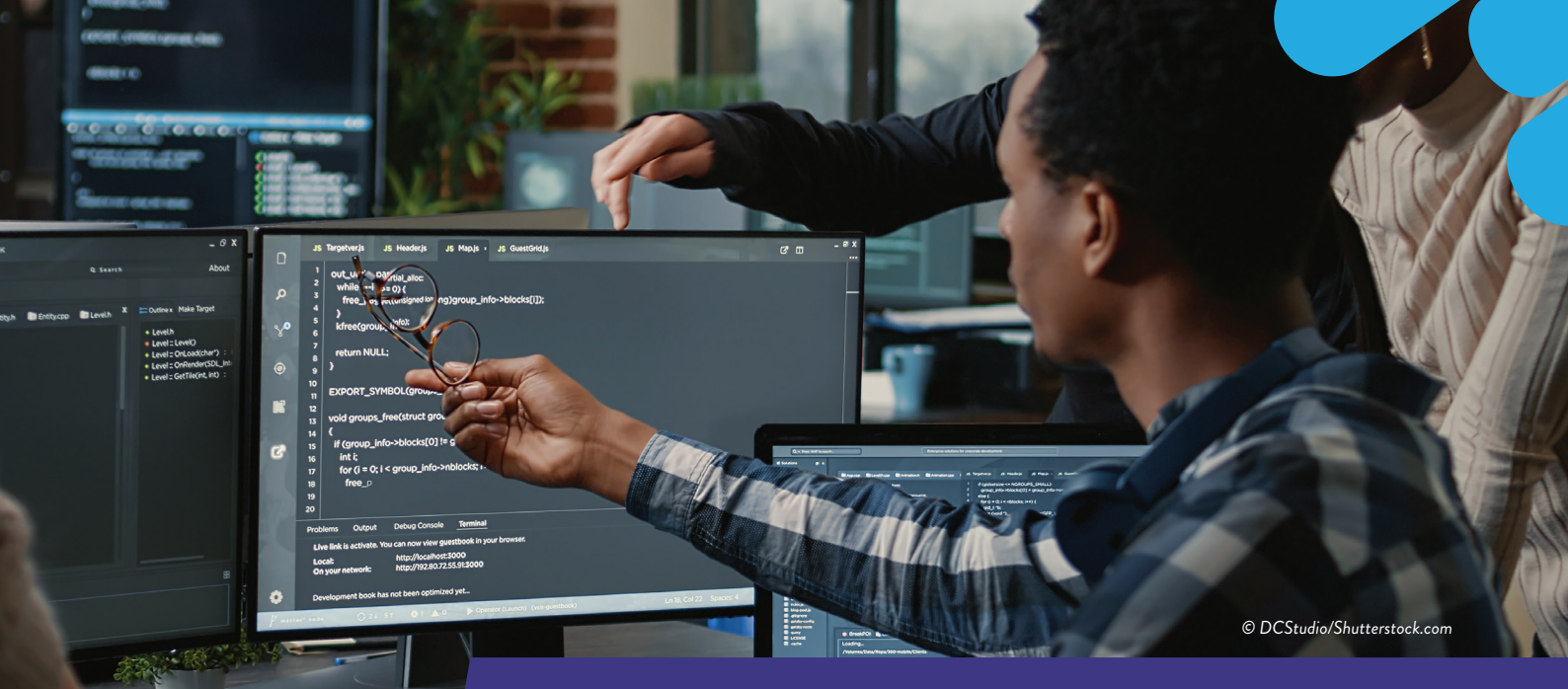
Many data scientists, computer scientists and researchers use Jupyter Notebooks to write and run code. Unlike traditional software development, where code is written in a file and executed from beginning to end, Jupyter Notebooks combine code, documentation and outputs such as graphs and tables in a single interactive document.

“Instead of one long script, the code is broken down into individual blocks called cells,” explains Thibaud. Users can run a cell and immediately see the results it produces.

This makes Jupyter Notebooks particularly useful for analysing large datasets, as researchers can quickly see how changing a variable affects their results without rerunning the entire code.

Why are Jupyter Notebooks prone to bugs?

Unfortunately, the flexibility of Jupyter Notebooks comes with a drawback. Users can run cells in almost any order, so they might run one cell, go back and change an earlier cell, then skip another cell entirely. This means the notebook may appear to



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work even though some parts of the code are missing or out of date. For example, a programmer might accidentally delete a cell containing an important variable, yet the notebook continues to work because that variable is still stored in the computer's temporary memory from an earlier run. Once the notebook is closed and reopened, the variable disappears and the code suddenly breaks. "This chaotic environment makes it remarkably easy to introduce subtle, hard-to-detect bugs that standard software tools aren't built to find," says Thibaud.

How is Thibaud detecting bugs in Jupyter Notebooks?

Traditional bug detection tools were designed for conventional software, so they struggle to accurately analyse Jupyter Notebooks with independent cells that can be run in any order. To address this challenge, Thibaud developed JupOtter, an AI-powered bug detection system specifically designed for Jupyter Notebooks. "Instead of analysing the entire project as a single unit, JupOtter uses AI models to examine code at the cell level," he explains. "It treats individual cells as self-contained blocks of logic while using AI to track how data flows and changes between those cells, catching hidden bugs that traditional systems completely miss."

Why is it important to refactor code?

Finding bugs is only one part of software maintenance. Developers also spend a significant amount of time refactoring code – reorganising and improving a

program's internal structure without changing how it behaves. "It is essentially a deep-cleaning and reorganising process for a program's codebase," says Thibaud.

Modern software systems can contain millions of lines of code and are often worked on by large teams of developers. Without regular maintenance, code can become disorganised and overly complex. Developers call this 'spaghetti code' because the different parts become tangled together, making the software difficult to modify and increasing the risk that a small change in one area will unexpectedly break something elsewhere.

Is AI better at refactoring than humans?

Thibaud and his team have been comparing how humans and AI refactor code by analysing software changes made by developers and AI coding agents. They found that human developers often make structural improvements, such as moving related pieces of code together or breaking large sections into smaller, reusable components. In comparison, AI agents spend most of their effort modifying annotations.

They also discovered that AI agents perform over 60 times more refactoring actions than humans. However, making more changes does not necessarily improve software quality. The team found that AI agents often repeatedly rewrite code to make it appear cleaner or to update annotations. While these changes may look productive, they can create a false sense of progress and increase

development costs without providing meaningful improvements.

In addition, despite making many more edits, AI agents did not consistently produce better code. AI introduced code smells – indicators of design flaws or potential bugs – at rates similar to human developers. "In fact, one AI agent was found to introduce a statistically significant increase in code smells after refactoring," says Thibaud. "Ultimately, we found that high-volume AI modifications do not correlate to genuine code improvement, meaning human developers still need to closely audit AI changes."

What role will AI play in the future of software engineering?

"There is a fear that AI is going to replace software engineers and developers," says Thibaud. "Based on our research and the current trajectory of autonomous coding tools, I think this is unlikely. Instead, AI will fundamentally shift what a software engineering job entails."

As AI agents become capable of generating larger amounts of code, software systems will become bigger and more complex. However, more code does not automatically mean better software. Developers will still need to ensure that AI-generated code is reliable and free from errors. The role of software engineers will shift away from writing every line of code and towards reviewing and testing code produced by AI systems, opening exciting new opportunities in the field.

About *software engineering*

Software engineering is the design, development and maintenance of computer software. The field combines problem-solving and technical knowledge to create the programs and applications that power everything from smartphones and video games to hospitals, banks and spacecraft.

Why is software engineering an appealing career?

Software engineering is an exciting field because it allows you to turn ideas into real-world tools and technologies. “It is one of the few fields where you can build something incredibly powerful out of nothing but an idea and a computer,” says Thibaud. “Software touches every domain, so you get the chance to work

in almost any discipline you can think of.”

What challenges will future software engineers be addressing?

The field is evolving quickly as AI becomes increasingly capable of generating code. While these tools can help developers work more efficiently, they also present new challenges. As AI systems produce larger amounts of code, software projects will become more complex. “The challenge won’t be generating code,” says Thibaud. “It will be managing the growing amount of technical debt and keeping increasingly complex software systems running smoothly over time.”

What does a career in software engineering involve?

“People often think that software engineers and developers spend all their time writing code, sitting alone in front of their computers,” says Thibaud. “This is far from true!” Instead, they work closely with product managers to understand what software should do and decide which features to prioritise. They also spend time reviewing other people’s code to search for logic errors, security weaknesses and potential bugs. And testing software is an important part of the job, helping to ensure that programs behave as expected.

Pathway from school to *software engineering*

At school, computer science and mathematics will help you build the foundation for software engineering by developing computational thinking, logic and problem-solving skills

“Software engineers spend a lot of time explaining technical concepts to clients and discussing complex code with collaborators, so strong writing and speaking skills are essential,” says Thibaud. “Don’t neglect subjects that will help you develop communication skills.”

At university, a degree in software engineering, computer science or computer engineering could lead to a career in software engineering.

Explore careers in *software engineering*

Software is found in every aspect of our lives, so there are software engineering career opportunities in every sector!

The best way to explore software engineering is by learning through practice. As well as watching tutorials, try building something you are interested in. “If you like video games, try to create a small computer game, or a mod for a game you like,” suggests Thibaud. “If you are part of a local club or organisation, try to build a website for them from scratch.”

Online resources can help you learn software engineering skills. Organisations such as freeCodeCamp ([freecodecamp.org](https://www.freecodecamp.org)) and Codecademy ([codecademy.com](https://www.codecademy.com)) include beginner-friendly courses related to programming and computer science.

Download Thibaud's resources from
futura-careers.com/can-ai-find-and-fix-hidden-software-bugs



Meet Thibaud

I have loved computers since I was a kid. As a teenager, I loved playing video games. I also enjoyed reading and playing table tennis and soccer with friends.

When I went to university, I initially studied chemistry for two years but I was not great at it. After that, I realised my favourite course during those two years was a course in computer programming. So I switched my degree to computer engineering. When I moved from France to Canada to study for my master's degree, I was fortunate to have a fantastic supervisor and lab mates who really made me fall in love with research in software engineering.

The part of my job as a software engineer that I enjoy the most is understanding a problem, breaking it down into small pieces and solving it. The most challenging thing is that software engineering is a field that moves extremely fast, meaning we always have to keep ourselves up to date with new technologies, hardware and changing user habits. To stay relevant and effective, software engineers must continuously adapt, step out of their comfort zones, and learn new technologies and programming languages.

In my free time, I love having fun and unwinding with my family and our pets (we have a cat and a dog). I also really enjoy playing board games and video games, hanging out with friends, reading and painting.

Thibaud's top tips

1. Don't be afraid of taking a non-linear path or changing direction in your education – learning what you don't like to do is still learning, and very important.
2. Many skills are transferable. When you learn something, think about how it can apply to whatever career you want to pursue.
3. Find mentors, professors or peers who challenge and support you. This will completely transform your career and make your work exciting – we can't succeed alone!

Exposing the beauty of mathematics with fractals

Fractals are intricate mathematical patterns that repeat forever. At **Université du Québec à Trois-Rivières** in Canada, **Assistant Professor Pierre-Olivier Parisé** has helped to expand a method to visually render fractal objects, showcasing the beauty of these intriguing patterns and enabling mathematicians to uncover the extraordinary mathematics that define them.



**Assistant Professor
Pierre-Olivier Parisé**

Department of Mathematics and Computer Science, Université du Québec à Trois-Rivières, Canada

Field of research
Mathematics

Research project
Developing a mathematical method to create and analyse 3D fractals

Funder
Natural Sciences and Engineering Research Council of Canada (NSERC) Discovery Grant RGPIN-2026-04740

Website
mathopo.ca

doi: 10.33424/FUTURUM714

What do trees, ferns and broccoli have to do with mathematics? The answer: they represent the mathematical concept of fractals – objects that repeat themselves at smaller and smaller scales. A tree trunk splits into large branches which split into smaller branches which split into twigs, while each fern leaf and broccoli floret is a miniature version of the whole fern frond or broccoli head.

Talk like a ...

mathematician

Fractal – an image or object that infinitely repeats itself

Render – to create a realistic computer-generated image

Ray tracing – a rendering technique that calculates the paths of individual rays of light through a computer-generated scene

Ray marching – an adaptation of ray tracing in which each ray is advanced along its path in steps

Distance estimator – a mathematical function used in ray marching to estimate how far a ray is from a surface

Multicomplex numbers – a multidimensional extension of complex numbers (imaginary numbers – the square roots of negative numbers – are examples of complex numbers)

Commutative – a system in which the order you apply an operation does not change the result (e.g., $a + b = b + a$)

“Strictly speaking, these natural examples are only approximate fractals as they repeat over a limited range,” explains Assistant Professor Pierre-Olivier Parisé, a mathematician at Université du Québec à Trois-Rivières. “In a true mathematical fractal, the object appears within itself infinitely, with new details that keep appearing no matter how far you zoom in.”

Previous mathematicians have created techniques to visually render 3D fractals, and Pierre-Olivier and his collaborators have built on these, which has involved developing new mathematical methods. “This

is, first and foremost, a piece of foundational mathematics,” he says, highlighting that one of the joys of being a mathematician is having the opportunity to simply push the boundaries of our knowledge. However, his technique can also be used for practical applications. “Fractals have always been good at drawing people into mathematics because you can appreciate their beauty without understanding them,” he says. “I hope these 3D images can serve the same purpose – showing that even something as forbidding as multicomplex analysis has a vivid tangible side that can simply be an object of art.”



What is ray tracing?

Ray tracing is a rendering technique used in computer graphics to produce realistic images (complete with accurate shadows, reflections and lighting) by simulating the physical behaviour of light. It calculates the paths that individual rays of light take as they travel through a scene to reach a viewer. However, as most light emitted from a source will scatter into the scene and never reach the viewer, tracing every ray from a light source would be a waste of computational power. Instead, the ray tracing technique starts from the viewer's perspective and traces rays backwards into the scene, calculating the path of one ray for every pixel in the image.

"Each ray is followed until it hits the first surface in its path, and at that point the program must work out what colour the pixel should be by gathering information about the lighting where the ray landed," explains Pierre-Olivier. To do this, the program casts a shadow ray to detect if the object is lit by the light source or if it is in the shadow of another object, plus a reflection ray to see what the surface reflects and a refraction ray to see how light bends through transparent objects. "A single frame in an animated film can require millions of rays which takes hours of rendering time but produces high quality images," says Pierre-Olivier. "For example, Pixar first used ray tracing for *Cars* in 2006 to render realistic reflections, shadows and metallic surfaces."

Why does ray tracing not work for fractal objects?

While graphic designers can use ray tracing to create realistic-looking objects in animated scenes, the technique does

“Fractals have always been good at drawing people into mathematics because you can appreciate their beauty without understanding them.”

not work for rendering true fractal objects. "The real difficulty appears the moment we pass to a genuinely 3D fractal," says Pierre-Olivier. "As a solid object sitting in space, to obtain a realistic image we must cast rays, find where each one meets the fractal object and light the surface it lands on." But this is where the assumptions built into ordinary ray tracing break down. Because fractals have infinite detail at every scale, no matter how far you zoom in, the computed ray will never actually reach the object's surface.

How does Pierre-Olivier render 3D fractals?

To solve the problem of rendering 3D fractals, graphic designers need to use an adapted version of ray tracing known as ray marching, where the ray is advanced along its path from the viewer into the

scene in steps, until it is close enough to the fractal to be considered to have reached the surface. At this point, the program follows the usual ray tracing technique to determine what colour the pixel should be. The length of each step in the ray marching technique is defined by a distance estimator – a mathematical function that estimates how far the ray is from the fractal at each step. "Producing such an estimator is a genuine mathematical problem," says Pierre-Olivier.

Inspired by a distance estimator found for complex numbers, Pierre-Olivier and his collaborators have developed a new mathematical method for calculating distance estimators that uses multicomplex numbers in a commutative number system that models higher dimensional space. "As a result, the properties of 3D fractals can be mathematically proved, rather than merely observed as an image on a screen," he says. "This means they can be rigorously analysed. The key value of this technique is that it provides a method for exploring the mathematics behind fractals."

Pierre-Olivier's work sits at the intersection between mathematical multicomplex dynamics and practical computer graphics, and he hopes both mathematicians and graphic animators will benefit from his distance estimator method to share the incredible beauty of mathematics with the world.

About mathematics

“Mathematics is one of the few subjects you can pursue with almost nothing but your own mind,” enthuses Pierre-Olivier. “Once you have learnt its language, you are free to wander wherever your curiosity leads.” For Pierre-Olivier, the hardest part of being a mathematician is not solving mathematical problems but finding the right problem to tackle in the first place. “I want to solve problems that are hard enough that cracking them will actually mean something,” he says. “Searching for a solution to a difficult mathematical problem feels like a quest! And the quest never ends, because every problem you solve opens new questions.”

What does the life of a mathematician look like?

“There is no typical day as a mathematician, and that is part of what I like about the job,” says Pierre-Olivier. “The popular image of a mathematician – someone standing alone at a blackboard all day – captures only a sliver of the reality.” As a researcher, Pierre-Olivier attends conferences to share his research with the mathematics community. “These conferences give me the opportunity to travel around the world and visit incredible places: Vancouver, Toronto, Nashville, Honolulu, London and more,” he says. As a teacher, he prepares and delivers lectures to classes and supervises students conducting research projects. “My record was teaching 147 students where the class had to be taught in an auditorium, like you

see in the movies *Beautiful Mind* and *Good Will Hunting*!”

What will the future of mathematics look like?

“It’s tempting to think that everything has been discovered in mathematics, but in fact there are more open questions today than ever before,” says Pierre-Olivier, so there are plenty of opportunities for the next generation of mathematicians. As with most areas of life, AI will play a significant role in the future of the field. “AI will help us with problems that demand long, intricate calculations,” predicts Pierre-Olivier. “With AI to carry that burden, mathematicians will be able to study problems in much greater depth than is currently feasible.”

Pathway from school to mathematics

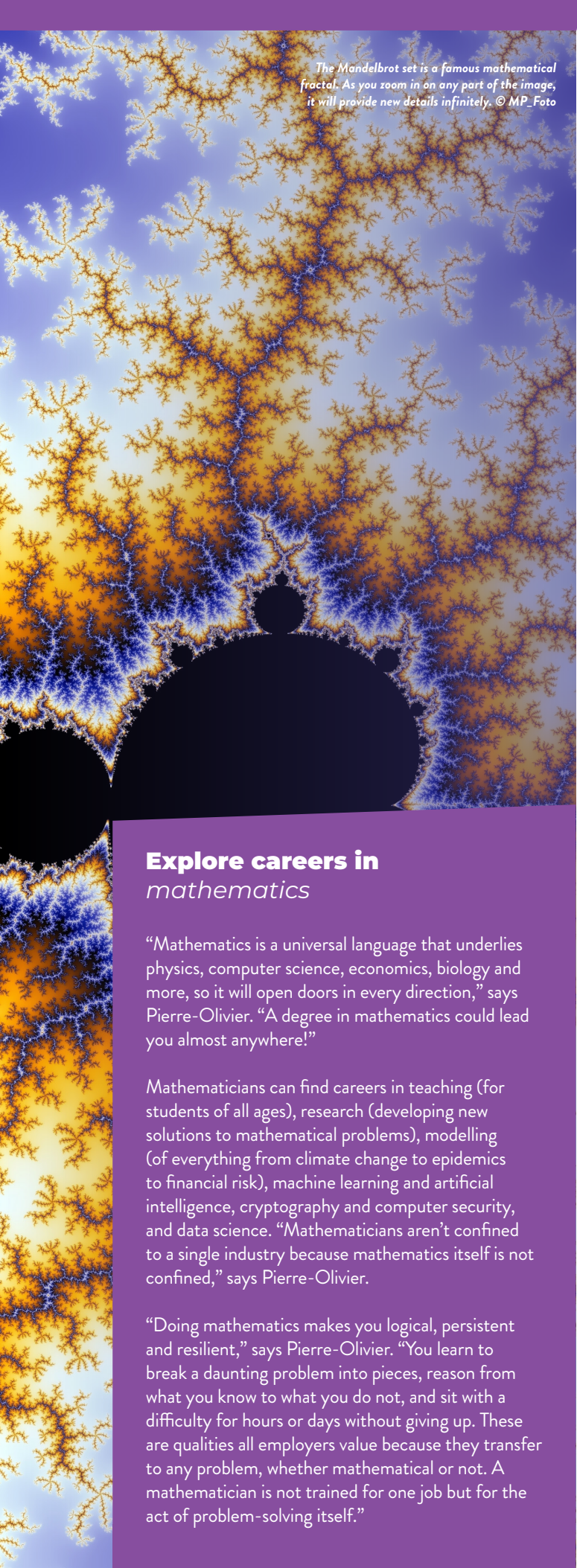
At school, study mathematics and physics. “Algebra, geometry and trigonometry will teach you the language of mathematics,” says Pierre-Olivier. “Physics is where mathematics comes alive as a description of the real world.”

“But more important than the subjects you study is learning to enjoy reasoning about hard problems,” advises Pierre-Olivier. “The most valuable habit you can acquire is the patience to understand why something is true rather than merely how to compute it.”

At university, study a degree in mathematics. Pierre-Olivier recommends taking courses in algebra, probability, real and complex analysis, topology, logic, and programming.

Download Pierre-Olivier’s resources from futura-careers.com/exposing-the-beauty-of-mathematics-with-fractals





The Mandelbrot set is a famous mathematical fractal. As you zoom in on any part of the image, it will provide new details infinitely. © MP. Foto

Explore careers in mathematics

“Mathematics is a universal language that underlies physics, computer science, economics, biology and more, so it will open doors in every direction,” says Pierre-Olivier. “A degree in mathematics could lead you almost anywhere!”

Mathematicians can find careers in teaching (for students of all ages), research (developing new solutions to mathematical problems), modelling (of everything from climate change to epidemics to financial risk), machine learning and artificial intelligence, cryptography and computer security, and data science. “Mathematicians aren’t confined to a single industry because mathematics itself is not confined,” says Pierre-Olivier.

“Doing mathematics makes you logical, persistent and resilient,” says Pierre-Olivier. “You learn to break a daunting problem into pieces, reason from what you know to what you do not, and sit with a difficulty for hours or days without giving up. These are qualities all employers value because they transfer to any problem, whether mathematical or not. A mathematician is not trained for one job but for the act of problem-solving itself.”



Meet Pierre-Olivier

When I was a teenager, I had little interest in school. Most of the projects we were assigned did nothing to draw me in. All of that changed, however, when I met two passionate and dedicated mathematics teachers.

The first teacher, Jean-Patrick Paul, moved me with his love of mathematics. He was always enthusiastic, and that enthusiasm became my own – it made me eager to tackle the problems he set for us. I was proud to bring him my solutions, because I knew he would be glad to see my progress and would be just as fascinated as I was by the answer. From that point on, I took my mathematics and physics courses far more seriously.

The second teacher, Denis Tremblay, was the one who ultimately shaped my decision to study mathematics at university. He nurtured my curiosity by offering me intriguing puzzles with captivating solutions. He introduced me to *Accromath*, a Quebec magazine that makes mathematical ideas accessible to a broad audience. A fire had been kindled in me – one that still burns today.

I first came across 3D fractal images during a summer research project at the end of my second year of university. A mentor, Professor Dominic Rochon, guided me through how to generate and rigorously study 3D fractals and the subject captivated me.

When I’m not solving mathematical problems, I enjoy biking with my wife and daughter. I surf when I can, and I’m learning how to wing foil. I also like repairing things around the house which brings some concreteness to my otherwise abstract work life. I’ve been an avid lover of *The Legend of Zelda* since I was young, and I still play it out of nostalgia, along with *Mario Kart*.

I love the fact that mathematics is alive! To study mathematics is to be handed a tool of extraordinary power and beauty to understand the world around us.

Pierre-Olivier’s top tips

1. Learn the foundations of mathematics and learn them well. Mathematics is built in layers, with each resting on the one below, and there are no shortcuts through the bottom layers. So take time to understand why things are true rather than merely how to use them.
2. The next generation of mathematicians will not be replaced by AI, but they will need to work alongside it. So learn how to use AI tools to do the long and mechanical parts of an argument while you keep watch over the ideas. A student who is comfortable both with a chalkboard and computational tools will be well placed to do mathematics in the years ahead.

How can Two-Eyed Seeing transform the way we teach?

In many classrooms, STEAM subjects are primarily taught through Western or mainstream scientific approaches. While these methods are powerful, relying on a single worldview can limit how students connect their learning to the world around them. To combat this, the Canadian organisation **IndigeSTEAM Society** is supporting teachers in adopting Two-Eyed Seeing – a framework that brings together Indigenous/traditional and Western/mainstream ways of knowing to create more meaningful, culturally-responsive learning experiences.



**IndigeSTEAM
Society**

Calgary, Alberta, Canada

Fields of research

STEAM education; Indigenous education

Project

Encouraging teachers to use Two-Eyed Seeing in their classrooms

Funders

Natural Sciences and Engineering Research Council of Canada (NSERC) PromoScience; Social Sciences and Humanities Research Council of Canada (SSHRC) Connections; Society for Canadian Women in Science and Technology; Indigenous Youth Roots; Stantec; University of Calgary; Heartland Generation Ltd

Website

indigesteam.ca

doi: 10.33424/FUTURUM707

Students and teachers bring their own experiences, cultural backgrounds and ways of understanding the world into the classroom. These perspectives can enrich how learning takes place across the curriculum – not least in STEAM teaching, which uses a ‘Western’ STEM framework. The IndigeSTEAM team is helping teachers explore new ways of approaching teaching through the framework of Two-Eyed Seeing.

Originally shared by Mi’kmaq Elder Albert Marshall, Two-Eyed Seeing refers to, “learning to see from one eye with the strengths of Indigenous knowledges and ways of knowing, and from the other eye with the strengths of Western knowledges and ways of knowing, and using both these eyes together, for the benefit of all.” Two-Eyed Seeing enables the recognition of traditional knowledge as a distinct and whole knowledge system side-by-side with the mainstream system. IndigeSTEAM recognises that Two-Eyed Seeing encompasses all school and career ‘topics’. It is more than Indigenous and Western worldviews and includes the voices of all human cultures.

Why multiple worldviews matter in education

When STEAM subjects are taught only through a single worldview, learning can sometimes feel disconnected from students’ lives and local environments. Students may master facts and formulas, but struggle to see how their learning relates to themselves, their communities or real-world challenges. “Two-Eyed Seeing students continue to develop academic skills, but gain relational and ethical understandings, which are essential for addressing real-world challenges,” says Kaylee Shannon.

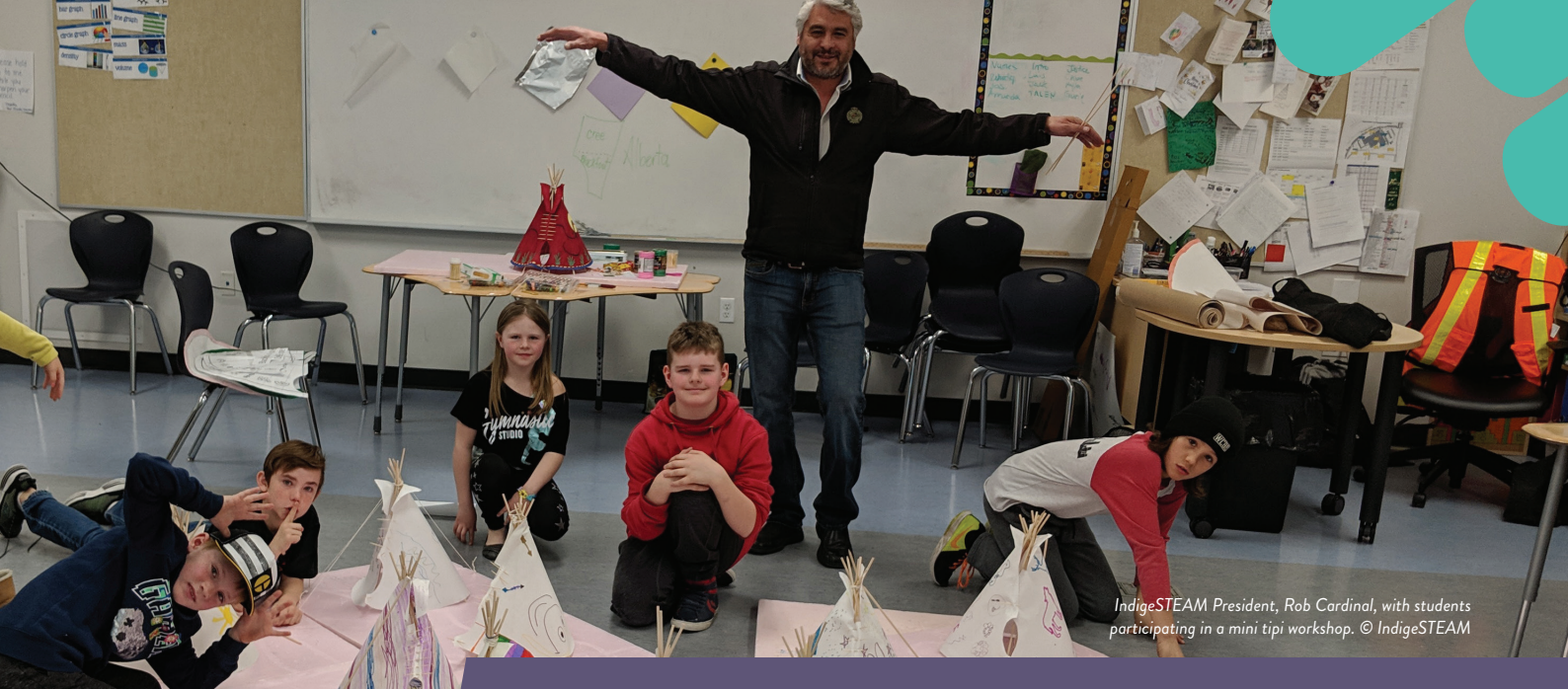
Teaching through Two-Eyed Seeing helps create space for a more complete understanding of

how knowledge connects to the world around us. When students engage with both mainstream and Indigenous/traditional ways of knowing, they begin to recognise that knowledge can be both evidence-based and rooted in relationships, lived experience and responsibility. Two-Eyed Seeing is restorative because it brings Indigenous/traditional knowledge back into its rightful place as an equal partner to mainstream subjects like science, challenging the assumption that there is only one valid way to understand the world. Students see that multiple truths can coexist, strengthening one another. “It’s a pedagogical approach – a framework – that brings the strengths of both ways of knowing together,” explains Izzy Ward.

Two-Eyed Seeing in practice at IndigeSTEAM

At IndigeSTEAM, Two-Eyed Seeing is experienced through hands-on programmes designed to bring Indigenous/traditional knowledge and mainstream STEAM learning together. “Through cultural teachings from community members side-by-side with guidance from scientific mentors and teachers, youth learn not only how the natural world functions through the two world views, but also to see the world with both eyes in a way that their Elders and scientist instructors cannot,” says Wendy Hutchins. IndigeSTEAM’s approach helps restore that balance by showing students and teachers





IndigeSTEAM President, Rob Cardinal, with students participating in a mini tipi workshop. © IndigeSTEAM

that Indigenous knowledge is not an add on, but a complete way of understanding the world that complements the mainstream framework.

IndigeSTEAM's best example of Two-Eyed Seeing teaching is their mini tipi workshop that combines tipi teachings with geography, history, symbology, mathematics, engineering, and many other aspects and focuses. A simple yet profound Two-Eyed Seeing concept is the side-by-side geometry of the circle and cone with Indigenous 'geometry' of the tipi shape representing a living human being: head, skin, ears, toes, teeth, mouth and more.

IndigeSTEAM sees the impact of Two-Eyed Seeing reflected in its alumni. Joe Wolfleg says, "It's a practical tool for transforming how we communicate and connect." For Joe, holding both knowledge systems together creates a greater perspective on the world, and has given him the confidence to move through Western spaces without having to question his Indigenous identity.

Two-Eyed Seeing in your classroom

"Two-Eyed Seeing recognises that each perspective offers valuable knowledge, and when they are used together, they can lead to deeper, more holistic learning and problem-solving," explains Kaylee. "Two-Eyed Seeing is not about simply adding Indigenous content to existing lessons," emphasises Sheila Norris. Instead, it invites teachers to reflect on how learning is designed so that multiple knowledge systems can be thoughtfully woven into the curriculum from the outset. For example,

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Two-Eyed Seeing recognises that each perspective offers valuable knowledge, and when they are used together, they can lead to deeper, more holistic learning and problem-solving.

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you could bring in scientists, speakers or story tellers from the local community, have students bring in stories from their cultural background, or include opportunities for place-based learning, where lessons are grounded in the local environment and students are encouraged to learn both from and about the land. It helps to ensure that learning remains connected to community knowledge and local contexts.

Rob Cardinal suggests making your teaching as authentic as possible: "Authentic teaching is actually teaching; it is not lecturing." Learning from authentic voices such as Elders, Knowledge Keepers and community members allows students to hear stories and teachings that go beyond what textbooks can offer. Two-Eyed Seeing teaching appreciates that Indigenous Peoples are living, evolving communities whose knowledge continues to shape STEAM today. Students learn that knowledge is relational – shaped by land,

community, identity and lived experience – and that learning becomes deeper when these relationships are honoured.

Two-Eyed Seeing as a way of being

Two-Eyed Seeing is more than an approach to teaching. "For teachers and students, this can look like approaching learning and decision-making with openness and humility by asking whose voices are included, whose are missing, and how different perspectives can work together," says Kaylee. Living Two-Eyed Seeing means recognising the history of how Indigenous knowledge was marginalised and understanding the responsibility we carry to restore its voice, authority and rightful place in STEAM education. "Students can see that you care about what you are teaching," says Rob. "Teachers should also be ready to learn right alongside their students."

Two-Eyed Seeing is not just another teaching tool, or something secondary to Western/mainstream ways of educating. "The teaching behind Two-Eyed Seeing comes from each person's identity, culture and lived experience to bring connection to each other and understanding on how our responsibilities are acted upon in the world," says Sheila. "Teachers and students can live Two-Eyed Seeing by being curious, listening deeply, honouring knowledge they carry from home, and being open to learning from the land and each other."

'Two-Eyed Seeing and other lessons learned within a co-learning journey of bringing together indigenous and mainstream knowledges and ways of knowing, Bartlett, Marshall and Marshall (2012) doi: 10.1007/s13412-012-0086-8

Advice for teachers

Getting started

Two-Eyed Seeing is best understood as something that grows through shared learning, relationships and ongoing reflection – rather than a method that can be learnt in a single training workshop. For teachers who are unsure how to begin, Two-Eyed Seeing does not require having all the answers in advance. “What matters is building authentic relationships and creating space for multiple ways of knowing in your classroom,” says Kaylee. This provides a space where every voice is heard and valued and shifts attention from delivering curriculum content to building relationships with students, the land and the wider community.

Working through challenges

Adopting a new teaching approach can feel unfamiliar at first, and it is normal for teachers to encounter challenges when exploring Two-Eyed Seeing in STEAM education. However, these challenges are not barriers, but starting points for reflection, learning and relationship-building. “Respecting the traditional knowledge is key. Appreciation is not appropriation,” explains Sheila. “Teachers are Knowledge Keepers who teach what they learn.”

“A common challenge is uncertainty about how to respectfully incorporate Indigenous perspectives without oversimplifying or misrepresenting,” says Rob. Building relationships can help address this, whether through connecting with local Indigenous communities, education teams, cultural organisations or Indigenous-led resources. Two-Eyed Seeing involves a shift in classroom relationships. Rather than a top-down model, it encourages shared learning where every voice is valued and the teacher is also a learner. This requires openness and vulnerability, as teaching becomes more relational and responsive. “When teachers are willing to be real with their students, Two-Eyed Seeing becomes something lived, not taught,” continues Rob.

It is important to acknowledge at the beginning of the lesson where the knowledge came from. “In a Two-Eyed Seeing way, we always acknowledge our teachers as we go rather than just giving

references at the end,” says Wendy. Assessment can be challenging with Two-Eyed Seeing approaches, just as it can with inquiry, problem or project-based learning. Consider oral, artwork or theatrical-based assessments.

Practical examples of Two-Eyed Seeing in STEAM education

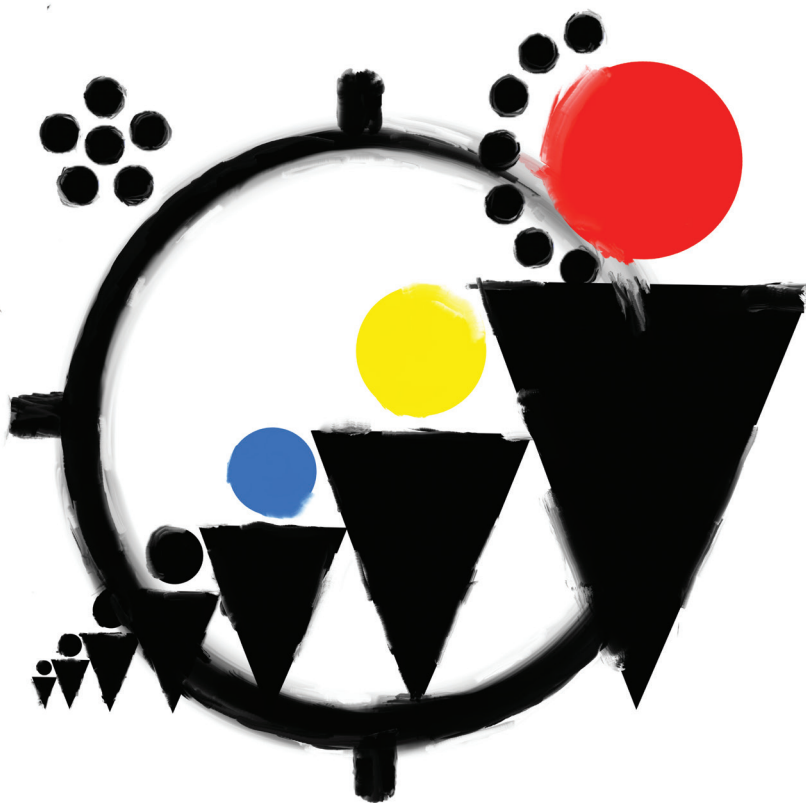
Two-Eyed Seeing can be woven into many familiar STEAM topics in ways that help students connect scientific concepts with relationships, responsibility and lived experience. “For example, when teaching the water cycle, students can explore the scientific processes of evaporation, condensation and precipitation through experiments, observations and diagrams,” says Kaylee. “At the same time, Indigenous knowledge offers teachings about water as living and sacred which connects all life.” Teaching could include local waterways, stories and discussions about caring for and protecting water. Together, these approaches help students understand water not only as a scientific

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When teachers are willing to be real with their students, Two-Eyed Seeing becomes something lived, not taught.

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system, but also as something deeply connected to community and the land. If on the land, students can explore topics such as navigation, plants, animals and ecosystems, while developing scientific skills such as observation and environmental testing. Ask the problem-based questions: ‘What problems do you see? What could we do? Should we?’ Let the students learn from each other.



Seven Generations, by Joey Big Snake.

“In this piece, I wanted to express how I understand and feel the practice of Two-Eyed Seeing in my own life,” explains Joey. “The figures represent the Seven Generations, showing how knowledge, responsibility and teachings move from those who came before us into the present and forward into those yet to come.”



Meet *the team*



Kaylee Shannon, Gambler First Nation, IndigeSTEAM Education Manager, BEd

Two-Eyed Seeing shapes the way I see and live in the world. It fuels my curiosity and reminds me that there's so much to learn. It guides how I live my life and how I teach my children to notice, respect and learn from the world in all its ways. I share the teachings and traditions I learnt from my grandparents with them, and we talk about what they mean today.



Sheila Norris, Cree Métis, IndigeSTEAM Executive Director, Education Assistant

I try to live in a way that honours relationships with people, the land and myself. This comes with a responsibility to consider how my actions will affect the next seven generations, so I approach situations with respect, love and humility. Two-Eyed Seeing is a reminder that I am strongest when I allow both ways of knowing to guide me. I do not have to choose between one way of knowing or another.



Wendy Hutchins, Ally, IndigeSTEAM Co-founder and Treasurer, PhD Microbiology and Immunology

As an educator, I believe learning must be relevant to students' lives or they will not see its importance. I learned more from reflection, reading and exploring in the world than from memorising facts for exams. Indigenous ways of knowing return us to older apprenticeship models, learning in the world, on the land, with a mentor, and with deeper thought than rote memorisation.



Izzy Ward, Métis, IndigeSTEAM Education Director, BSc Neuroscience, MEd

As an Indigenous person, I am guided by our traditional ways of knowing and being, and Two-Eyed Seeing helps me hold that cultural knowledge alongside my work in Western science and education. Living this way gives me confidence and harmony in how I understand the world, and it helps Indigenous learners see their culture reflected in their academic studies.



Joseph Wolfleg, Siksika First Nation, IndigeSTEAM Youth Project Manager and Alumnus

I live Two-Eyed Seeing by using both my cultural teachings and my learning together in everyday life. My culture guides how I understand relationships, responsibility and community, while STEAM helps me understand how things work. Two-Eyed Seeing gave me the confidence to be myself in every space; I do not have to choose between worlds. It showed me that my identity and the knowledge I carry from home are strengths I can use in school, work and with the younger students I support.



Rob Cardinal, Siksika First Nation, IndigeSTEAM Co-founder and President, BSc Astrophysics

Two-Eyed Seeing has become a natural part of how I view the world. It shapes how I approach people, situations and challenges. It gives me a broader, grounded perspective and reminds me to move with humility, respect and gratitude – values that guide my relationships and decisions.



Joey Big Snake, Siksika First Nation, IndigeSTEAM Artist in Residence, BFA Media Arts & Digital Tech

For me, Two-Eyed Seeing is about carrying Indigenous and Western ways of knowing with respect, allowing them to support one another without one overpowering the other. It is a way of walking in both worlds while staying grounded in culture, spirit and community. My artwork reflects that relationship and the responsibility of carrying teachings forward in a good way.

How does metacognition affect learning?

Metacognition is a skill that develops throughout childhood and adolescence. As people grow, their ability to accurately judge their knowledge and to act on these judgments tends to improve. However, some students find this metacognitive monitoring and control difficult, and this can impact their ability to learn. In Switzerland, a research team led by **Professor Mariëtte van Loon** at the **University of Zurich** and the **University of Basel** is investigating the links between students' metacognitive skills and their ability to learn.



Metacognitive Development Research Group

Project description

Investigating the impact of metacognitive monitoring and control on learning in children and adolescents

Institutions

Department of Psychology, University of Zurich;
Faculty of Psychology, University of Basel,
Switzerland

Field of research

Developmental cognitive psychology

Funder

Swiss National Science Foundation



Professor Mariëtte van Loon

Faculty of Psychology, Department of Human Development, University of Basel

doi: 10.33424/FUTURUM715

Download Mariëtte's resources from
futurumcareers.com/how-doesmetacognition-affect-learning



Why are some students better at learning than others? Traditional thinking points to differences in cognitive abilities, such as intelligence, memory or processing capacity. But one research group, led by Professor Mariëtte van Loon, is looking at this question from a different angle by studying how metacognition affects students' ability to learn.

What is metacognition?

"Metacognition is an umbrella term for the ability to reflect on and regulate your own thinking and learning processes," explains Mariëtte. "Specifically, my team focuses on how children and adolescents monitor and control their learning." Monitoring refers to a student's ability to evaluate what they do and do not know, while control refers to their ability to take actions to improve their learning.

"It's a bit like how a thermostat keeps the temperature in a room constant," says Mariëtte. "The thermostat needs to constantly assess the temperature and then, based on that monitoring, take an action, such as heating the room up or cooling it down." This is a process that, once developed, happens automatically. For example, as you read this article, you might come across a passage that you don't immediately understand and decide

to read it again. That is monitoring and control in action.

How does metacognition develop?

"Metacognitive abilities develop substantially throughout childhood and adolescence," explains Mariëtte. "As people grow, their ability to accurately judge their knowledge and to act on these judgments typically becomes more refined."

But children do not grow and develop at the same rate, and the same holds true for their metacognitive abilities. "Some students are better at monitoring where they are doing well and where they have gaps in their knowledge," says Mariëtte. During a reading task, for example, these students are able to assess how well they are understanding the content and go back to re-read sections they didn't understand. "But other students might just go through the information without monitoring how well they're understanding it," continues Mariëtte. "They go through a task, but they don't question themselves and they don't recognise their errors."

These metacognitive abilities can have a huge impact on a student's ability to learn. "Some years ago, one meta-analysis indicated that metacognitive processes are at least as important as intelligence when it comes to academic achievement,"





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says Mariëtte. “Our research findings with adolescents suggest a similar pattern. Although intelligence is an important predictor of learning, metacognitive monitoring and control skills also influence how well students learn and perform academically. These skills make a unique contribution above and beyond intelligence.”

How does the team study metacognition?

“The main question that we want to answer is: Why are some students better than others at monitoring and control?” says Mariëtte. “But we also want to dig deeper than this. We want to understand more about these metacognitive skills and answer different research questions.”

For example, Mariëtte’s team wants to figure out if monitoring and control are skills that can be applied in the same way across different tasks – be it reading, maths or learning a language – or if these skills are task-specific. They also want to investigate the relationship between these two skills: Are monitoring and control really separate skills, or are they two parts of one overarching skill?

With these questions in mind, Mariëtte and her team collaborate with schools to conduct their research. “Our research is based on cognitive psychology, but instead of working in a lab, we do our research in school contexts,” explains Mariëtte. “We get students to complete a learning task and ask them to judge how certain they are that their answers are correct and how likely they are to retain the information.”

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Although intelligence is an important predictor of learning, metacognitive skills also influence how well students perform academically.

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The team also records which parts of the task the students are focusing on and which items they return to in order to improve their learning. “We also have competitions in which students receive points for correct answers and lose points for incorrect answers,” says Mariëtte. “When assessing metacognition in this way, it encourages students to carefully reflect on the accuracy of their answers.”

In many cognitive psychology experiments, participants must complete tasks under time constraints and without the chance to re-visit their answers. But Mariëtte and her team do things a little differently. “We combine controlled experiments with research on self-regulated learning, where students can take their learning into their own

hands,” explains Mariëtte. “In our tasks, students can decide for themselves how long they spend on each item, reflect on their learning and spend time re-studying to improve their responses. In this sense, it is much closer to an actual school environment, where learning is not something that happens only once, but is ongoing and can be adapted.”

What has the team discovered?

“In a recent study, we found that most children have age-appropriate skills that develop over time,” says Mariëtte. “However, there was a small group of students who lagged behind in metacognitive development and struggled to assess their own learning and take subsequent actions to improve it.” What’s more, as other students’ metacognition developed over time, this group struggled to improve.

These findings have led to many more questions that Mariëtte and her team want to answer. “Do some children show persistent difficulties in metacognitive development? Is it something that we can reliably identify and diagnose? How can we accurately spot the children who need support?” asks Mariëtte. “We are finding answers in our research, but when we find them, we always have more questions!”

One question in particular immediately suggests itself: What can teachers do to support students who struggle with metacognition?

Advice for teachers

“Our research focuses on individual metacognitive monitoring and control processes,” says Mariëtte. “But of course, students’ learning is shaped by many factors, including school culture and classroom management.” These suggestions draw on metacognition research and may help you think about how you can support students whose metacognitive abilities are still developing.

Identify struggling students

Current evidence suggests that teachers do not always accurately estimate their students’ monitoring and control skills. “While teachers are able to identify students with good metacognitive skills, they often find it more difficult to spot those who are struggling,” says Mariëtte. “Studies have found that this is often because teachers judge their students’ abilities based on information that is not directly indicative of their metacognitive skills.”

For example, some teachers base these judgements on how active the student appears in class, how engaged they are with learning tasks or how good their grades are. “Gender and ethnic background also seem to play a role,” says Mariëtte. “Teachers tend to underestimate boys a little more than girls, as well as students from minority backgrounds.”

Mariëtte suggests that the best way to assess your students’ metacognitive abilities is to observe how well they assess their own work. “Simply asking students to score their own answers can give you lots of information about how good they are at distinguishing between errors and correct responses,” says Mariëtte. “It is important for students to be able to identify their mistakes, but it is equally important for them to recognise where they gave the right response, as they might lose confidence and motivation if they think that they are always getting things wrong.”

Provide opportunities for practice

“It is important to create opportunities for your students to practise their monitoring and control skills,” says Mariëtte. “Some research has found that teachers tend



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These suggestions draw on metacognition research and may help you think about how you can support students whose metacognitive abilities are still developing.
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to offer low-performing students fewer opportunities to practise self-regulated learning, which can prevent them from improving their monitoring and control skills.” It is important to support the metacognitive development of all students.

Some specific interventions have been shown to improve students’ monitoring. Although this evidence comes mostly from experiments in controlled settings rather than classroom environments, these interventions offer a theoretically-grounded place to start.

For example, in learning aimed at retrieval, the use of delayed judgement and self-scoring can be effective. Ask your students to evaluate how well they remember each item after a short delay, rather than immediately after studying. This will allow them to more accurately identify which

information they have and have not learnt. “When learning is aimed at comprehension, generation tasks may be more effective,” says Mariëtte. “Ask your students to generate summaries, concept maps or diagrams shortly after studying information. These tasks can help students gain insights into how well they understand concepts and their relations to each other.”

Create opportunities for feedback

One of the most effective influences on both monitoring and control is feedback. “While younger students benefit most from immediate, clear and specific feedback, older students can benefit from feedback framed as reflective questions,” says Mariëtte. “Prompting children to think about how they approached a task, which strategies they used and how they reached their conclusions supports their ability to monitor their learning.”

Explicitly training students to use control strategies also appears to be effective. “Teaching students to study strategically – such as spending more time on difficult items and ignoring irrelevant information – can help them make better control decisions and achieve better learning outcomes,” says Mariëtte. “Although more classroom-based research into control processes is needed, our research team is actively investigating this topic and

Meet *the team*



Dr Emely Hoch

Postdoctoral Researcher,
Department of Psychology,
University of Zurich

I study learning and cognitive processes in an applied context. Understanding how metacognition develops can help bridge the gap between basic research and practical applications in education.

In the future, I would like to better understand how we can support the development of metacognitive abilities in children. I hope this research contributes to effective educational interventions

that may prevent learning difficulties and support academic success.

While metacognitive processes are important, they should be considered alongside other aspects of self-regulated learning, including motivation, goal setting and emotional regulation. To achieve a full understanding of learning, we must consider these interconnected processes.



Dr Leila Schächinger

Postdoctoral Researcher, Faculty
of Psychology, University of Basel

I study how late elementary school children monitor and control their own learning. My research examines these processes across different activities, such as memory, reading and problem-solving tasks.

I am fascinated by why some students learn more effectively than others. By studying how monitoring and control skills differ between individuals, we may be able to develop interventions that are better tailored to students' needs. My motivation is to contribute to educational practices

that help all students reach their full potential.

I am particularly interested in how students can learn successfully when they are still learning the language of instruction used at school. Many students around the world learn in a language that is not their strongest, which can make learning more challenging. I hope to discover how metacognitive skills can support these students and identify strategies that help them learn effectively despite language barriers.



Eileen Rüegg

PhD Student, Department
of Psychology, University of Zurich

I am studying how metacognition is related to other factors that matter for learning, such as memory, intelligence and learning goals. I am interested in which of these factors make a unique contribution to learning, where they overlap and how they influence each other.

I have always been interested in cognitive development because it helps us understand processes that are central to being human: how we think, learn and make sense of our surroundings. Once they get over the

abstract term, people often think back to their own experiences in school: how they studied, what worked for them and where they struggled. The connection between a rich and complex research topic and these familiar everyday experiences is fascinating.

I am interested in how metacognitive skills can be assessed reliably in educational contexts. There is a need for practical diagnostic tools that could help practitioners better identify which students may benefit from additional support.



Katharina Zimmerman

PhD Student, Department
of Psychology, University of Zurich

I investigate how different psychological processes – such as emotional, motivational and cognitive states – interact with metacognition. A further goal of my work is to formalise verbal theories of metacognition to better understand the underlying mechanisms that drive these processes.

I love being able to contribute to a large collaborative project. I am particularly

interested in understanding developmental trajectories and how they relate to learning. Being part of a collaborative research team allows us to examine these questions from different perspectives.

In the future, I hope to better understand why metacognitive abilities differ across individuals and contexts. This will help us identify factors that support effective learning.

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