

CHANGEMAKERS AND LEADERS

JAIDEN CORFIELD

The 20-year-old who founded a mental health organisation for boys is leading a youth project for Ashoka and the Edge Foundation

ALSO IN THIS ISSUE

SHAUN MCINERNEY

ARCHITECT OF ASHOKA AND THE EDGE FOUNDATION'S NEW CAPABILITIES FOR A NEW WORLD PROGRAMME

CHANGEMAKER HEADTEACHERS

SCHOOLS IN GREATER MANCHESTER, UK, ARE ON A CHANGEMAKING JOURNEY

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WELCOME

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CHANGEMAKERS AND LEADERS

In 1981, Ashoka, an international, non-governmental organisation dedicated to supporting social entrepreneurship, sent out its first newsletter with the headline ‘Changemaker’. Since then, the term has entered common usage. But what does it actually mean?

According to Ashoka, a changemaker is someone who “imagines a new reality, takes action and collaborates with others to bring that new reality into being for the good of others”. Ashoka envisions a world where everyone is a changemaker and identifies and supports social entrepreneurs who are leading the way in this regard. In the UK, for example, Ashoka has partnered with the Edge Foundation to pilot a changemaking and leadership programme for schools in Greater Manchester (p 38). Only a few months in, headteachers and their students are already experiencing a positive impact (p 62).

Jaiden Corfield (p 4) is leading the youth side of the programme, which is called New Capabilities for a New World. Jaiden, who also founded The Outliers Project, a mental health organisation for boys, shows us that there is no defined or ‘right’ path to success and that everyone can become a changemaker and leader.

The researchers in this issue are changemakers and leaders, too. The projects they are working on require imagination, action and collaboration to make new realities happen. As Dr Alice Alipour, Associate Professor of Civil, Construction and Environmental Engineering and creator of shape-changing buildings, says, “Never stop dreaming. The world’s most challenging problems need people who can think outside the box.”



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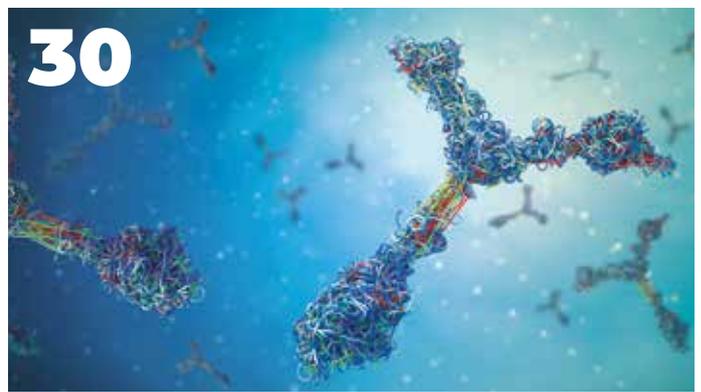
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“A LOT OF STUDENTS FEEL THAT SCHOOL ISN'T EQUIPPING THEM FOR LIFE BEYOND SCHOOL.”

20-YEAR-OLD **JAI DEN CORFIELD** IS LEADING A YOUTH PROGRAMME FOR **ASHOKA** AND **THE EDGE FOUNDATION'S NEW CAPABILITIES FOR A NEW WORLD PROGRAMME**, AND HAS FOUNDED A MENTAL HEALTH ORGANISATION FOR BOYS. HE TELLS US WHY HE IS ADVOCATING FOR CHANGE IN EDUCATION AND BEYOND





*Jaiden leading a masculinities and well-being project in 2019 on behalf of The Reclaim Project.
Photo credit: The Reclaim Project*



WHAT IS YOUR ROLE ON THE NEW CAPABILITIES FOR A NEW WORLD PROGRAMME?

We bring headteachers and young people together to help them create solutions for social change within the education system. Shaun McInerney, my colleague at Ashoka (see **Are we giving young people the capabilities they need to succeed?** (p 38)), is leading a programme with headteachers, where he's taking them on a learning journey to reconnect with themselves, their school and young people.

I'm leading a programme where we're taking young people on a journey to understand what changemaking and leadership mean. The aim is to help them connect with themselves as a student and leader so that they can work with their headteachers to create solutions that work well for their school.

HOW MANY YOUNG PEOPLE ARE YOU WORKING WITH?

I'm working with 21 students from eight schools in Greater Manchester. Each school nominated a maximum of four students and the 21 students, who are in years 8-12, were chosen from this list.

WHAT CHANGES DO YOUNG PEOPLE WANT TO SEE IN THEIR SCHOOLS?

Lots of things, but the biggest issue is careers education. A lot of students feel that school isn't equipping them for life beyond school. And there's a clash because a lot of teachers believe they are doing that.

Young people want more than the curriculum. They want to learn how to pay bills, what college is like, the differences between college and university, and what the options are if they don't want to go to university.

Then there's well-being. School can sometimes feel like a stressful place. The students I'm working with just want to know how to breathe during stressful periods and they don't feel like school equips them to do that.

WHAT HAVE BEEN SOME OF THE OUTCOMES OF THE PROGRAMME SO FAR?

We've been working together for six months now and we've gone from not understanding a lot about leadership or changemaking to creating learning journeys with headteachers. Some young people now have weekly meetings with their school leaders where they're discussing things they can change, like discrimination, and they feel a lot more confident engaging with teachers.

There has also been a shift in students' mindsets. They initially saw themselves as representatives of their schools and therefore wanted to show it in the best light possible, but when you're creating change, that's not always the best way of approaching it. Now, the students focus on thinking about what needs to change within their school for their peers to feel they belong in school or within the education system.

WHAT ARE THE HIGHLIGHTS OF THIS PROGRAMME FOR YOU?

The biggest transformation for me has been seeing individuals, and the mutual understanding between teachers and students, really grow throughout this programme.

Students and teachers understand each other a lot more. They understand that they both want to see changes within the education system, whereas, before, they were almost working against each other. Young people don't think teachers want the same thing as them and teachers don't think young people are ready or prepared to deal with a huge amount of change.

ABOUT JAIDEN

“

“IF I COULD TELL YOUNG PEOPLE ONE THING, IT WOULD BE THAT IF YOU HAVE A VISION OR WANT SOMETHING CHANGED OR WANT TO BE A LEADER, YOU’RE DEFINITELY CAPABLE.

”



Jaiden delivering a speech at his Virgin Young Changemaker Graduation. Photo Credit: The Virgin Money Foundation

When I was 11 years old, I joined a youth group and started doing activism. From that, I went into campaigns and spent a few years trying to create as much change as I possibly could, mainly in education and amplifying the voices of working-class young people.

My route into activism started with an assembly at my school where they were talking about a summer school for young people that explored leadership. I wasn't really bothered about the leadership part but there was going to be free food. I was like, if there's free food, I'm there!

I grew up on the fifth most deprived estate in the UK. I became really engaged with the concept of leadership at the summer school because it wasn't a concept we were familiar with on my estate.

A mentor introduced me to Ashoka and I've been involved with the organisation for two years now. Ashoka was looking to expand its reach in Greater Manchester with its Everyone a Changemaker movement. I joined as the first young co-leader.

I studied A-levels in politics, philosophy and sociology because I felt these subjects were a natural path for someone like me who is interested in social change. But if I had that time again, I would study things that don't necessarily follow the trajectory of the traditional changemaker.

I would've liked to have studied arts subjects like fashion or graphic design but it didn't feel like it would be accepted to have studied these subjects if I wanted to follow an academic path, or get into changemaking or social policy.

I went to university for one year and then dropped out. Sometimes, people think you have to do a higher education degree if you want to get on, but, for me, higher education is something you should really love. I was studying politics, philosophy and economics (PPE) during the COVID pandemic but I wasn't enjoying university, so I decided to drop out to start up a mental health organisation called Outliers.

It was an incredible honour for me to have been selected for the Virgin Money Foundation Changemaker graduate programme. Virgin chose 10 young people to go on this journey – young people who were creating change in their communities – and brought them together to research and work on an idea they had pitched to Virgin.

I was able to use the £10,000 given to me by Virgin Money to start Outliers in Salford. They also provided us with mentoring. I started the Virgin Money Foundation programme very much a visionary, someone who had ideas for social change but didn't necessarily know how to put them in place to make them happen. The mentoring team was great at helping me make things happen.

I paint a positive image of what it means to be me as an individual but there are definitely days when I don't feel that positive, or when the social impact sector feels overwhelming and I'm burnt out.

I suffer from anxiety, and have done for the past 2-3 years, but more so in the last year. When it's less severe, I'll go for a walk or start doing the things I love, but there are days when it's really severe and I'm bedbound. For me, being able to recognise how I'm feeling, accepting it and sitting with it for a while, is really helpful. When it's more severe I'll take the day off work and focus on relaxing.

One thing I wish I'd known when I was younger is that I'm capable. If I could tell young people one thing, it would be that if you have a vision or want something changed or want to be a leader, you're definitely capable. It's about believing in yourself and placing yourself in positions where you can seek and take advantage of opportunities when, or if, they arise

The best advice I've been given is from Kelly Davies at Ashoka. She always ends with the phrase 'crack on'. Just do it and see what happens. If you fail, get back up, crack on again, and keep going. Those two words, crack on, are teaching me a lot about positive resilience.

JAIDEN TELLS US ABOUT HIS OUTLIERS PROJECT

Outliers works with boys aged 10-18 to explore masculinity, leadership and well-being. I did a dissertation on the evolution of masculinities at college for sociology and that's when I really started to understand masculinity. It's then I understood that young men – or our generation, as a whole, – are at a turning point with mental health and mental illness, and it's kind of overwhelming.

I spent about six months talking to over 150 people from across the world, trying to learn as much as I could about working in the mental health and well-being sector. After I'd done the research, I registered Outliers as a charity, formed a group, joined a mentoring programme, and now it's an organisation.

Outliers is launching in three areas: Salford, Rochdale and Bolton. Salford was known as the gun and gang capital of the UK for a very long time and, in the past couple of years, it's had a 200% increase in youth violence and crime. However, Salford also has a really beautiful community and many of its young people are aching for opportunity. There's a venue called the Salford Lads Club. Boys will go to the club to explore leadership, well-being and positive models of brotherhood. We encourage them to look at brotherhood in a different light and explore solutions to the challenges in their community.

In Rochdale and Bolton, we've been leading well-being sessions with young people in schools. We take different approaches in each area, depending on what we think young people need.

A lot of boys are new to the idea of leadership and believe it isn't for them. The plan is to take them on a full journey of understanding themselves as a leader, someone who can have an idea for change, lead or form a team, build new approaches to that change and be able to lead towards it. We'll guide them towards models of good leadership and bad leadership, and place them in positions where they can improve their public speaking, teamwork and planning skills.

I think everyone has the capability to be a leader, or can be taught to be a leader. I then think it's down to you to decide which type of leader you wish to be.

JAIDEN'S HATS

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www.thelisteningfund.org

Knowledge Powers Change (KPC) Impact Fund
Leader for The INKEY List

Lead Facilitator for Beyond Equality
www.beyondequality.org



Jaiden on a panel at a Robert F. Kennedy Human Rights Convention in 2021.
Photo Credit: The Robert F. Kennedy Foundation

DOES THE WAY WE FUND SCIENTIFIC RESEARCH BENEFIT EVERYONE EQUALLY?

FUNDING AGENCIES ALLOCATE MONEY TO SCIENTIFIC RESEARCH PROJECTS WITH AIMS THAT COULD BENEFIT SOCIETY. BUT HOW DO WE KNOW WHAT THE FULL EFFECTS OF RESEARCH ARE, AND WHO THESE BENEFITS REACH? **DR THOMAS S. WOODSON**, ASSOCIATE PROFESSOR AT **STONY BROOK UNIVERSITY** IN THE US, STUDIES THE BROADER IMPACTS OF RESEARCH. BY UNDERSTANDING BROADER RESEARCH IMPACTS, WE CAN IMPROVE THE WAY THAT FUNDING IS ALLOCATED TO ENSURE THAT BENEFITS FROM SCIENCE REACH THE PEOPLE WHO MOST NEED THEM

TALK LIKE A SCIENCE AND TECHNOLOGY POLICY RESEARCHER

PUBLIC POLICY — an approach, including rules, principles and plans, formally adopted by a government or another institution to tackle a certain issue (such as healthcare)

FUNDING AGENCY — an organisation which allocates a certain amount of money, known as a research grant, to scientific research projects to pay for scientists, lab equipment, etc.

RESEARCH ABSTRACT — a brief written summary of a research project, which includes a description of the methods and outcomes, often at the start of a longer report, with further details about the research

IMPACT — an effect or consequence

INEQUALITY — an unequal distribution of resources or opportunities among members of a society

MARGINALISED GROUPS — people who are regularly excluded from certain aspects of society or ignored, which often results in them being disadvantaged economically and in other ways

MACHINE LEARNING — using and developing computer algorithms (sets of instructions), which can improve automatically over time through finding patterns in large datasets

Organisations like the US National Science Foundation (NSF) fund scientific research which aims to have positive impacts on society, such as developing new green technologies or more reliable materials. However, currently, we know very little about what kinds of impacts different research projects have and who they affect. Dr Thomas S. Woodson, of the Department of Technology and Society at Stony Brook University, studies these impacts. Thomas believes that by finding out who currently benefits from scientific research, we can reduce inequalities in the future and ensure that science has wide-reaching positive impacts on society.

WHY SHOULD WE STUDY THE IMPACTS OF SCIENTIFIC FUNDING?

Throughout its history, science has provided many benefits to people, for example through the development of technologies like computers. Thomas says, “Science agencies want to find more life changing discoveries!” Government funding agencies allocate money provided by taxpayers, so the agencies also have a responsibility to spend those funds on research that people will benefit from. Therefore, agencies like the NSF monitor the impacts of the research they fund.



DR THOMAS S. WOODSON

Associate Professor, Department of Technology and Society, Stony Brook University, USA



FIELD OF RESEARCH

Science and Technology Policy



RESEARCH PROJECT

Investigating the broader impacts of scientific funding



FUNDERS

National Science Foundation (NSF), National Aeronautics and Space Administration (NASA)

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WHICH IMPACTS ARE IMPORTANT?

The NSF awards research funding to projects based on two main criteria. Thomas explains that the first, called intellectual merit, describes the novelty of the research project (how new and creative it is), while broader impacts (BIs) describes how the project can have positive impacts on society.

Some research projects fulfil both criteria well, while others do not have many BIs. “I think it is okay for some projects not to have clear broader impacts,” says Thomas. “Many science experiments and discoveries have no clear broader impact, but it is important to keep learning new things. Also, many scientific findings do not have a clear use when they are first discovered, but, over time, they become extremely important for society.”

However, Thomas thinks that when research projects do have BIs, it is important that we have a good understanding of what they are and who they affect. He is investigating two aspects of BIs which are currently not monitored by the NSF. They are inclusion, which considers who will benefit from the research, and immediacy, which looks at how closely related BIs are to the actual science behind the research.

HOW DO YOU STUDY BROADER IMPACTS?

Thomas and his research students have read the abstracts and summary reports of 400 research projects funded by the NSF, analysing whether the BIs are inclusive. “For example, in these abstracts and reports, if the scientists said that their research could help poor or marginalised groups, then we classified it as having inclusive broader impact,” says Thomas. During their analysis, Thomas and his team also

classified BIs at different levels of immediacy. When the BI is the purpose of the research, it is classified as an intrinsic impact. For example, developing malaria medicine is an intrinsic impact of scientific research with this aim. Training students to conduct research would be classified as a direct impact – it occurs as a direct result of the research project, but it is not its purpose. The BI is extrinsic if it is totally unrelated to the research project. For example, if a physicist visits a school to give a talk about careers in science.

However, Thomas says that it can be difficult to understand the short- and long-term impacts of a research project using this method. For example, there might be long-term impacts that are not written about in abstracts or project reports.

WHAT ARE THE STUDY FINDINGS, SO FAR?

Thomas’ research finds that, currently, BIs tend to benefit advantaged groups of people (those with more money and power) over the general population or marginalised groups. He explains, “Developing a new technology is very expensive. If a company wants to make money from its new technology, its best option is to develop and sell it to people with money and power.”

This means that new technologies resulting from scientific research benefit advantaged groups more than other people, so there are inequalities in the ways BIs are distributed. However, as Thomas says, “There is a lot of research that helps everyone regardless of status. For example, developing a smart grid will help both rich and poor.”

Thomas and his research students are also examining the relationship between BIs and

how productive scientists are. He says, “There’s often the worry that if a scientist has spent a lot of time on broader impacts, they’re not spending time doing their research.” But, he reports that, based on his team’s findings so far, this does not seem to be the case. This evidence suggests that there are not really downsides to scientists ensuring positive broader impacts from their research, which is good news!

WHAT ARE THE NEXT STEPS FOR UNDERSTANDING BROADER IMPACTS?

If the research team can develop a way to use machine learning to analyse BIs based on key words, it could scale up its research substantially. One of Thomas’ students is trying to use machine learning to analyse 20,000 abstracts! “As you can imagine, that’s much more challenging because there’s lots of noise in the data and room for many errors,” says Thomas.

ABOUT SCIENCE AND TECHNOLOGY POLICY

Researchers working in society and public policy are interested in how policies set by governments or other institutions impact people. Their research highlights where policies can be improved, so can have a direct impact on decision making. Thomas has a particular interest in how technology can impact inequality across the world and how policy can help to reduce inequality.

HOW CAN TECHNOLOGY IMPACT INEQUALITY?

Thomas says that technology can reduce inequality if used correctly. “Over the past 50 years, the quality of life for poor and marginalised groups keeps getting better,” he

explains. “However, it is easy for technology to only benefit the rich and powerful, so government, industry and citizens must work to make technology equitable.”

WHO WILL BE THE NEXT GENERATION OF SCIENCE AND TECHNOLOGY RESEARCHERS?

It could be you! Thomas explains that to tackle the world’s policy challenges such as those related to climate change, we need a variety of perspectives. This is true for all research, and there is not just one type of person who can or should be a scientist. For example, if advantaged scientists from rich countries focus their efforts on

developing technologies for rich people, then we will never solve big problems such as humanitarian crises. “That is why I think there is a bright future for scholars from around the world; it is increasingly apparent that we need a variety of viewpoints and solutions,” says Thomas.

WHAT ARE THE REWARDS OF SCIENCE AND TECHNOLOGY POLICY RESEARCH?

Having the opportunity to positively impact policy and decision making is one of the main reasons Thomas enjoys his research. He says, “I also like that my research allows me to travel and talk to people from around the world.”

EXPLORE CAREERS IN SCIENCE AND TECHNOLOGY POLICY

- It is important that anyone wanting to study science and technology policy is interested in current events and reads the news. Reliable media outlets like the BBC or The Economist discuss issues related to science and technology. Thomas also recommends reading journals like *Science*, *Nature*, *Popular Science* or *Wired*.
- You can seek out information about decision makers in your area (for example, local government) or non-governmental organisations that campaign on policy issues to find out current relevant topics and areas of debate. Look on their websites or ask if there are placement opportunities.
- Visiting a university with a research department related to science and technology policy is the best way to find out about a research career. Thomas explains that his university, Stony Brook, has many opportunities for students aged 12-18 to visit the campus, learn about research and experience the university.
- Visit www.stonybrook.edu/summer/audience/high-school-students and www.stonybrook.edu/commcms/stem-smart/k-12/step to find out more.
- The average salary for an academic researcher in the US is around \$75,000 to \$100,000, but salaries usually start lower than this at the early stages of a career and increase with experience.

PATHWAY FROM SCHOOL TO SCIENCE AND TECHNOLOGY POLICY RESEARCH

Science and technology policy researchers come from all sorts of backgrounds – Thomas did a degree in electrical engineering before studying public policy.

- Thomas says that it is most important for students to learn how to ask questions, think and be persistent: “Those qualities make the biggest difference in being a researcher in science, technology, society and public policy.”
- It is important that you have an interest in research and how the world and policy works. Taking classes in policy, statistics, economics and sociology can help you develop relevant skills and knowledge.

HOW DID THOMAS BECOME A SCIENCE AND TECHNOLOGY POLICY RESEARCHER?

WHAT WERE YOUR INTERESTS WHEN YOU WERE GROWING UP?

I was interested in science and maths. I liked reading *Popular Science* magazine and learning about new technology.

WHAT LED YOU TO STUDY SCIENCE POLICY?

It was a big challenge for me to know what to study at university! I chose to study electrical engineering because I liked science and was drawn to computers more than cars and planes. When I was a kid, there was a movie called *Minority Report* with Tom Cruise and he used his hands to move a digital interface around. I thought it was the coolest thing ever! That's why I went into electrical engineering, as opposed to say, mechanical or aerospace engineering.

However, engineers are very focused on one particular problem, they go into a lot of detail, which they have to do to solve problems. But I really wanted to see how technology impacts people. This led me to study science policy.

HOW HAVE YOUR EXPERIENCES IN DIFFERENT PARTS OF THE WORLD INFLUENCED YOUR RESEARCH?

Before I did my PhD, I had the chance to work at a materials science laboratory in Nigeria. Every day at around 2pm, the

electricity cut out. As you can imagine, no matter how talented a scientist you are, if you have no power from 2pm to 4pm every single day, it's going to negatively affect your work. That experience got me thinking about how policy problems are impacting science and technology development. Reliable power is not a challenging technical problem – we've solved that – but it is definitely a social problem. When I came back from that trip to Nigeria, I decided to study public policy for my PhD. Now, my work merges science issues with policy.

WHAT ATTRIBUTES HAVE MADE YOU SUCCESSFUL AS A RESEARCHER AND PROFESSOR?

I think the most important attributes are persistence and the desire to learn new things. Every researcher faces setbacks, so it is important to learn from these errors and try something new.

HOW DO YOU OVERCOME CHALLENGES?

Like everyone else, I've faced several challenges in my career, whether it is failing an assignment or not being selected for a programme. A major way that I have overcome these challenges is by reminding myself of what is ultimately important. I am a Christian, so I believe that there is a loving God who cares for me. Being a successful researcher and scholar is not what gives me

value. When I feel like a failure, I remind myself of where I derive my value.

I also think it is extremely valuable to have other hobbies and activities that you can enjoy outside of work. Right now, I have a young son, so I spend a lot of my free time playing with him and doing household chores.

WHAT ARE YOUR PROUDEST CAREER ACHIEVEMENTS, SO FAR, AND YOUR AMBITIONS FOR THE FUTURE?

My proudest career achievements are finishing my PhD and earning tenure, which is a permanent position, at my university. Both of those tasks took years to complete, and it is an honour to achieve them. In the future, I want to find more ways to help technology improve the lives of marginalised people, and I want to see more young people reach their full potential.

THOMAS'S TOP TIP

Be curious and study something that you find interesting. I started off in engineering but switched to science policy because I felt more passionate about that topic.

PROSECUTING RAP: CAN WE GET RACIAL DISCRIMINATION OUT OF THE COURTROOM?

WHEN YOUNG BLACK MEN AND BOYS ARE ACCUSED OF CRIMES, RAP MUSIC IS OFTEN PRESENTED AS EVIDENCE. THIS IS A PRACTICE THAT AN INTERNATIONAL NETWORK OF SCHOLARS, INCLUDING PROFESSOR EITHNE QUINN FROM THE UNIVERSITY OF MANCHESTER IN THE UK, HAS FOUND TO BE STRUCTURALLY RACIST

GLOSSARY

PROSECUTE – to charge someone of a crime and present evidence against them in court

DEFENCE – (in court) the argument that the accused person should not be found guilty

DEFENDANT – the accused person in a court of law

FAIR TRIAL – a trial that is conducted justly and in which the defendant is afforded their full rights

STRUCTURAL RACISM – rules or systems in a society that result in unequal treatment of people depending on their race

DISCRIMINATION – treating a person unfairly because of who they are, including in relation to race

RAP ARTISTRY – rap skill, quality, craft or creativity

PERSONA – a character or role that someone takes on, not the same as and often confused with their true personality

FIRST PERSON – narrative voice using the pronoun ‘I’

BADMAN – an ultra-masculine, often violent persona

CRIMINOLOGY – the study of crime, criminals and criminal justice

CAMARADERIE – a sense of togetherness and friendship

Think about the music you listen to, the videos you watch or the games you play. Do they include references to bad behaviour? It might be that there are some lyrics or scenes that you would not be comfortable sharing with your parents because they involve violence, drugs or theft, for example.

Now, imagine the police found you had written stories or lyrics about these themes and they used them to help to suggest that you are a

criminal. This might sound unfair, but it is a reality some people face in the UK. In dozens of court cases, rap music videos or lyrics are used as evidence that a young person broke the law. Rap music is predominantly a Black youth form of artistry and, consequently, most of the defendants in such cases are young Black people. Eithne Quinn, a professor of cultural studies at the University of Manchester, is an expert on race, justice and culture, and she has shed light on this problem through her research

project, “Prosecuting Rap: Criminal Justice and UK Black Youth Expressive Culture”.

HOW DOES RAP END UP IN A COURTROOM?

Making music is hardly a crime, so you might find it surprising that rap can find its way into a court of law. However, this is happening, and more frequently so, during trials involving serious crimes such as assault, robbery or murder. Police investigators help the prosecution by looking for evidence against suspects, which can include trawling the internet and searching mobile phones for things they have written or videos they have made or appeared in.

When the investigators come across rap music lyrics or videos, they sometimes find references to violence and submit this as evidence that the suspect is a violent person. Rap music lyrics are usually written in the first person, so it might sound like the rapper is talking about things that they have done or want to do. For example, lyrics that say “I’m going to shoot you” could be used to suggest that the rapper was planning a murder in real life.

Unfortunately, this logic is flawed. As you will know from books you have read, just because an author uses the first person does not mean that they are writing an autobiography! Furthermore, despite the fact that crime and violence are common themes in other types of pop-culture (such as action films and video games), only rap is regularly used as criminal evidence. This concerns Eithne because she



EITHNE QUINN

Professor of Cultural Studies,
University of Manchester, UK

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FIELDS OF RESEARCH

American Studies, Criminology,
Cultural Studies

.....
RESEARCH PROJECT

Investigating the use of rap music lyrics and videos as evidence for the prosecution in criminal trials

.....
FUNDER

Arts & Humanities Research Council (AHRC)

Professor Quinn was a leadership fellow of the AHRC (2020-21). This project was funded by an AHRC Leadership Fellowship, Prosecuting Rap: Criminal Justice and UK Black Youth Expressive Culture [AH/T000058/1].

of the unfair use of rap music as evidence in court. They believe the first step is to ensure the defence closely scrutinises and challenges the rap music evidence when the prosecution tries to use it. The network is raising awareness about this troubling phenomenon and is building the capacity of independent experts who can explain the context of rap music lyrics properly to judges and juries in court cases. The network hopes that if academics and lawyers keep working together, they can vastly reduce the amount of music material getting as far as the jury.

The network's ultimate goal is to see structural changes. Eithne and her colleagues would like to see changes in the case law and in the guidance from the Crown Prosecution Service to make it much harder to present rap as evidence. The network hopes that these changes will make the courtroom a fairer place for everyone.

believes it “unduly targets the expressive forms of young Black people”.

IS RAP REALLY ABOUT VIOLENCE?

For many young people, rap is the music of rebellion and partying, and the lyrics can address themes of racism, inequality and alienation. Many young people face discrimination and a lack of opportunities, a situation that is all too common in one of Europe's least equal societies.

Rap does have some autobiographical elements and it often insists rhetorically on ‘keeping it real.’ But it would be a mistake to assume that rap lyrics are true stories. The truth is that rap – the most streamed type of pop music in the world – is big business, and part of its success lies in sticking to a familiar formula. This formula includes the image of authenticity, but also standard phrases about crime and violence which are tweaked, reused and exaggerated over time. Eithne describes the result as “a highly performative type of music that expresses emotions, entertains, and hopefully makes artists some money”, which “should certainly not simply be taken as a personal testimony”.

WHAT HAPPENS WHEN RAP IS USED AS EVIDENCE?

Unfortunately, the nuances of rap music culture are not obvious to UK jurors (who are mostly white and have an average age of about 50). Eithne explains, “When rap music videos are played in courtrooms in the midst of evidence about a violent incident, a literal reading of the lyrics can become compelling.” Instead of hearing fictional tales and repeated refrains, the jury members can too easily believe they are listening to confessions of guilt.

There are some cases where a rap song could have relevance to a crime. For instance, when a

rap video that includes an insult about someone could incite retaliatory violence. But, even then, the danger is that playing the music in court, in the context of evidence about a violent incident, makes the connection between violent lyric and actual violence seem much stronger than it is.

Many lawyers worry that this type of evidence has ‘prejudicial value’, as it plays to the emotions of the jury in ways that unduly damage the defendant's case. Some types of rap music, such as drill, can be intimidating to the jurors if they have not heard it before.

Stereotyping plays a big part. Whether or not the jurors are aware of it, they are being encouraged to associate Black culture with criminality – something that Eithne believes should be completely “shut down” in court. It does not help that the evidence is often presented by a police officer who is introduced as an ‘expert’ on rap material. This means that if the defendant gives a different interpretation of the rap music lyrics, it is, in many cases, their word against that of the police.

Eithne believes that the loose way rap is used in cases with multiple defendants, to cast a tone on proceedings against all the defendants, is structurally racist. “The use of rap music as evidence in court against groups of defendants is particularly dehumanising. It leads to some really murky thinking in cases that have life-changing consequences for the defendants,” she says.

HOW CAN WE CHALLENGE THE USE OF RAP IN COURT?

Eithne has collaborated with a number of colleagues including sociologist Dr Anthony Gunter, African American culture expert Professor Erik Nielson and law scholar Dr Abenaa Owusu-Bempah, to tackle the issue

MEET THE 'PROSECUTING RAP' NETWORK

**DR ABENAA
OWUSU-BEMPAH**



Associate Professor of Law

*The London School of Economics
and Political Science, UK*

*Fields of research: Criminal Law
and Criminal Evidence*

I am a legal academic with an interest in criminal law, but I have also been a fan of rap music for most of my life. When I learnt that rap music is used as evidence in court, I was interested to find out how and why. My expertise in law allows me to assess whether admitting 'rap evidence' is consistent with the rules of evidence and principles of fairness in a criminal trial.

Analysing court cases is interesting and intellectually challenging! I search online databases for cases where rap music was used as evidence, then analyse the facts and the legal arguments, taking notes and identifying patterns as I go. My analysis shows that, in England and Wales, rap music lyrics are often treated as 'bad character evidence' in serious cases involving weapons or violence.

My biggest concern is that racial prejudice could result in wrongful convictions. Rap music is primarily used as evidence against young Black people in a way that feeds into racist stereotypes that associate them

with crime. We don't see juries being given other violent genres of music as evidence.

Rap music should not be used as evidence if it is not relevant to the case! A key factor is how specific the lyrics are – do they include factual information about the crime? Before allowing prosecutors to use rap as evidence, courts should also consider the prejudicial effect – is the jury likely to think rap is stronger evidence than it is? Although change is slow, our work is raising awareness and changing perceptions. Hopefully, we'll soon see rap music evidence appearing much less often.

One important issue facing the next generation of legal researchers will be the impact of technology, potentially including virtual trials. Conducting court proceedings online can be more efficient than in-person, but it can also lead to victims, witnesses and defendants feeling excluded or unable to engage properly.

HOW DID ABENAA BECOME A LAW PROFESSOR?

When I was younger, I had a range of interests from music (I played the trumpet for a while) to art and sports. I'm not sure that I had a keen sense of justice, but I would get upset when I felt someone had been mistreated by the authorities.

From the age of 15 or 16, I wanted to become a criminal defence lawyer. I think I was inspired by the knowledge that innocent people get convicted, and that the criminal justice system can be harsh and unfair. I also watched a lot of legal dramas on TV.

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Mostly, I work independently and have control over my research agenda, which is great, but it requires a lot of focus, self-discipline and perseverance.

My proudest achievement is completing my PhD. It was a long and intense process, but it gave me the confidence to become a researcher. As for the future, I would like to continue working to improve outcomes for the most vulnerable people in the justice system.

PATHWAY FROM SCHOOL TO LAW

- Law has many different areas (such as criminal, corporate, family, IT or human rights) so it is helpful to take a range of subjects.
- English, history and philosophy can help prepare you well for a law degree.
- To find out more, look for work experience, volunteer at a law centre, or go to watch a trial and see the law in action.
- Keep in mind that studying law does not mean that you have to become a lawyer! Many law graduates go on to work in other sectors, including business and finance, politics and international development.

DR ANTHONY GUNTER



Senior Lecturer (Associate Professor)
in Childhood and Youth Studies

The Open University, UK

Fields of research: Youth Studies,
Criminology and Criminal Justice

I am interested in using research to understand real-world social issues. I draw on my experiences as a youth and community practitioner to engage with young people ‘on Road’ (on streets) or in youth clubs, residential activity centres, schools, colleges and Youth Offending Institutes. I write fieldwork diaries based on my observations, and I also record semi-structured interviews where I ask about a certain theme, but the participant can also speak freely.

My findings indicate that urban youth culture – including rap – plays a largely positive role in young people’s lives. It provides camaraderie, entertainment and a strong sense of identity. The ‘street gang’ label is used to criminalise large numbers of innocent young Black males. In reality, these ‘gangs’ are just neighbourhood friendship groups. There is no academic agreement on the existence of gangs, or whether gangs cause crime.

Instead of criminalising street gangs, government policies should support young people through employment, education and training opportunities, but, in recent years, youth support services have seen their funding cut.

Through my research, I hear from young people and their families about their lived experiences – from voices who are pushed to the margins and largely ignored by mainstream society. There is also international travel; I have undertaken research in Jamaica and the US and presented my findings to conferences in Sweden and Japan, for example.

HOW DID ANTHONY BECOME A YOUTH STUDIES RESEARCHER?

help themselves, and a passion for social justice have got me to where I am today. My career highlights have been working with communities to establish much needed services, and my first published book which was based on my PhD topic.

Growing up, I was a massive hip-hop fan, and also very interested in politics and Black popular culture, so I suppose it is no coincidence I am doing what I am doing now!

I was a ‘disaffected’ young man who hated school and, in fact, left school with only one equivalent GCSE in English. I went to college and studied GCSE sociology where I learned that kids like me were set up to fail. This was a eureka moment where I became committed to working (as a street-based youth worker) with

so-called disaffected young people like myself.

When I became a youth worker, I became concerned about the negative portrayal of Black British youth in the media. I wanted to demonstrate that Black youth were not essentially criminal, bad or less intelligent than young white people. So, I embarked on a PhD to prove just that... and here I am now.

Perseverance, curiosity, an interest in people’s lives, wanting to help others to

PATHWAY FROM SCHOOL TO YOUTH STUDIES AND CRIMINOLOGY

- At school or college, study social science or humanities subjects (such as law, sociology, politics, anthropology, history or human geography).
- At university, degrees are available in criminology, childhood and youth studies, and youth work. Learn more at thecompleteuniversityguide.co.uk

However, university does not have to be your first step. Anthony recommends you engage in your local community: “I started off as a volunteer at my local youth and community centre, and it literally changed my life.”

MEET THE 'PROSECUTING RAP' NETWORK

**PROFESSOR
ERIK NIELSON**



Professor of Liberal Arts

University of Richmond, USA

Field of research: *Literature
(African American literary and
musical traditions)*

My research explores the relationship between Black culture and the law in the US. As part of this research, I stumbled onto a disturbing phenomenon: prosecutors were using rap music lyrics as evidence in criminal cases, effectively punishing young men (almost exclusively young men of colour) for their art. The more I investigated this, the more I realised that it wasn't an isolated practice — it was, and still is, pervasive.

It's very common for rap lyrics to be used in American courts. Our research has identified several hundred cases, although we know there are many more if we include investigations, indictments, sentencing hearing, and plea deals, as well as trials. Until we know the full scale of 'rap on trial', it's difficult to estimate its impact on conviction rates. However, we have found that when rap lyrics are used, even when other evidence may be lacking, defendants are very likely to be convicted.

In pre-trial reports or in-court testimonies, I explain the history of rap music as an art form. Drawing on my academic training, which includes degrees focused on English Renaissance literature, as well as African

American literature, I inform courts of the complex musical and poetic conventions that underpin rap music. Reading rap music lyrics literally is no less foolish than reading other fictional genres that way.

At this point, I have worked on nearly 100 cases. As an expert witness in court, I see that prosecutors rely on the unstated assumption that the young Black and Latino defendants aren't capable of producing sophisticated art. This perpetuates stereotypes about young men of colour — stereotypes that are behind their mistreatment in the criminal justice system more broadly.

I see young men punished for their creativity, and I think about my own sons. As white children, they are unlikely to be in that position. This issue reveals one of the many double standards that have come to define our broken legal system.

It is an uphill battle, but interest in our research is growing. In New York, for example, two state senators have introduced legislation intended to limit the use of rap music as evidence. That's one state out of fifty, so there's plenty more to do on that front.

HOW DID ERIK BECOME A PROFESSOR OF LIBERAL ARTS?

Growing up, I was interested in music and sports, and little else! My success has come, in part, by not always following the conventions of academia. For example, rather than focus all my energy on publishing in scholarly journals, I have tried to write in places that are more publicly accessible. That has led to more real-world impact.

PATHWAY FROM SCHOOL TO LITERATURE AND AMERICAN STUDIES

- Alongside literature, a range of courses could help you to explore different ideas. Erik explains, "Some of the music and sociology courses I took as an undergraduate influenced me to take my career in this direction."
- American Studies is a cross-disciplinary field — like French Studies or Chinese Studies, it is known as an 'area study' and it includes a mix of culture, history, politics and literature.
- To get into an American studies degree programme, choose subjects like sociology, media studies, politics, history and English literature.
- Read, watch and listen! US popular culture, media and politics have a huge influence on global culture.
- For opportunities in the UK, check the UK-US Fulbright Commission (@USUKFulbright), the US Embassy in London (@USAinUK) and US Studies Online (@BAASUSSO) on twitter.

**PROFESSOR
EITHNE QUINN**



*Professor of Cultural Studies
University of Manchester, UK*

Fields of research: *American
Studies, Criminology,
Cultural Studies*

As the author of a scholarly book on ‘gangsta rap’ music, I started being approached by lawyers who needed expert advice at short notice. A lot of the work is writing reports about the rap lyrics and videos that the prosecution wants to use as evidence in the courtroom. This forces you to write in a clear and straightforward way (a good exercise for academics, who are notorious for writing long and convoluted sentences!).

I have given evidence in our criminal courts including at the Old Bailey (Central Criminal Court) in London. Given the chance, I’ve found jurors are often open to hearing a more complex account of rap music evidence. For instance, a rap music line that sounds, on the face of it, like a specific cold-blooded threat, can turn out to be simply lifted from the verse of a famous rapper that the defendant admires. Evidence that seems relevant to the case and damaging to the defendant can suddenly be exposed as irrelevant and simply part of a creative practice.

However, I have also seen jurors shocked by violent themes when rap videos are played to them in courtrooms. Videos often feature groups of young men making violent boasts and looking hostile. That’s the drill formula! It is very open to misreading and can easily become a menacing courtroom soundtrack.

I believe that far too many young people of all colours are being locked up in the UK. Our prison population has expanded massively since the 1980s. We often voice concern about ‘mass incarceration’ in America, but we need to turn our gaze to look at what’s going on here in our own criminal justice system. Many children grow up in poverty, even though we are one of the richest countries in the world. We should be investing in our children rather than using their art to criminalise them.

HOW DID EITHNE BECOME A PROFESSOR OF CULTURAL STUDIES?

Like most kids, I loved music growing up. I liked house music and rap. I did American Studies for my first degree at the University of Manchester (the same department where I am now a professor). During my third year as an undergraduate, I wrote my first ever essay on rap music. I didn’t do terribly well on it, but I enjoyed researching and writing it.

Why did I focus on American studies? The truth is, I fancied a year of study in the US! If you do American Studies, you can get to study in America – I went to Washington DC

and it was a really important and formative experience in my life.

After I published my book on rap music, which was based on my PhD thesis, I was asked by defence solicitors to explain the music genre in court cases. At first, I questioned whether I had the relevant expertise or could communicate it in the right way. Stepping into a different professional arena with high stakes was scary.

I’m naturally an introvert, so I’ve had to find my voice to speak in court. I really like to make

connections between different areas of study. Although I’m based in American studies, I’ve also worked in cultural studies and film studies, and I now have strong interests in criminology and socio-legal studies.

Aside from the ‘Prosecuting Rap’ project, my proudest achievements have been in teaching. I love to see students engaging and developing their own ideas. As lecturers, we can learn a great deal from students.

EITHNE’S TOP TIPS

- **Follow your nose.** Choose options that you enjoy, feel strongly about and are likely to perform well at. Move beyond the classroom and pursue your interests.
- **Sometimes, it’s the things that stretch us that turn out to be the most valuable.** Once I started serving as an expert in court cases, I learnt so much and so quickly. I felt I could make an impact in an area I felt strongly about.

EXPLORING THE LIFE AND WORKS OF ROBERTO GERHARD, THE ELECTRONIC MUSIC PIONEER

WHILE WE MIGHT THINK OF ELECTRONIC MUSIC AS A NEW STYLE THAT HAS EMERGED IN RECENT DECADES, ITS ROOTS CAN BE TRACED BACK MUCH FURTHER, TO WHEN ELECTRONIC EQUIPMENT FIRST BECAME AVAILABLE. AT THE UNIVERSITY OF HUDDERSFIELD IN THE UK, PROFESSOR MONTY ADKINS AND DR SAM GILLIES ARE EXAMINING THE WORK OF ONE OF THE KEY PIONEERS IN THE FIELD – ROBERTO GERHARD. BY DIGITISING HIS RECORDINGS, THEY ARE CREATING AN ACCESSIBLE ARCHIVE TO BRING GERHARD'S MUSIC, AND THE CHARACTER OF THE MAN HIMSELF, TO A CONTEMPORARY AUDIENCE

TALK LIKE AN ELECTRONIC MUSICIAN

DIGITISATION – the process of converting analogue media into a digital format

ELECTRONIC MUSIC – any music involving electronic processing, such as recording or editing

MIXER – sometimes called a mixing desk, a device that can take various audio sources and combine them to produce different outputs

MODERNISM – in music, a broad time period encompassing much of the 20th century, involving innovative approaches to reinterpreting 'traditional' musical techniques

SYNTHESIS – the process of creating sounds using electronic signals

TEXTURE – in music, how different aspects are combined in composition to determine an overall quality of sound

TIMBRE – the 'tone colour', or perceived sound quality, of a musical note

Electronic music is prevalent everywhere in today's world, from films to clubs to personal playlists. Despite this ubiquity, like anything, electronic music has its roots – and Roberto Gerhard was one of the first composers of this new musical style in the mid-20th century. At the University of Huddersfield, Professor Monty Adkins, Professor of Experimental Electronic Music, and postdoctoral researcher Dr Sam Gillies, are working to bring Gerhard's music and inspirations to public prominence.

THE MAN BEHIND THE MUSIC

As with all artists, Gerhard's work was heavily influenced by the circumstances of his personal life. Born in 1896 in Catalonia, a region of northern Spain with a strong independent identity, he spent his student days studying in Vienna and Berlin with the composer Arnold Schoenberg. "When Gerhard returned to Catalonia, he was seen as a leading modernist – someone who was doing something really new in music," says Monty. "However, he remained passionate about his homeland and his work referenced a lot of Spanish and Catalan folk melodies."

In 1936, the Spanish Civil War began in earnest. With nationalist forces threatening the mostly republican Catalonia, Gerhard and his wife made the difficult decision to leave their home country. They travelled first to Paris and then to Cambridge, and from the 1940s Gerhard was

working as a freelance composer in England. "Gerhard's exile meant that he had to take on a lot of jobs writing music for theatre, radio, and later, film, as well as composing for the concert hall," says Monty. "It was because he was writing a lot of incidental music that he became interested in electronic sound."

GERHARD'S MUSICAL CAREER

In the 1940s and 1950s, the range of electronic recording equipment available was very limited. "Gerhard originally used a Panatrope, an early record player, to play recorded instrumental cues for theatre productions," says Sam. "He then began using his own tape machines to record all kinds of sounds and transform them." Gerhard's novel use of electronic sound for a 1955 production of Shakespeare's *King Lear* created public excitement in England and beyond, kick-starting his work with major organisations including the BBC and the New York Philharmonic Orchestra.

Gerhard was one of the very first people in England to create a home electronic music studio. "When fully developed, Gerhard's home studio consisted of one microphone, five reel-to-reel tape machines, and a five-track mixer," says Sam. This sounds very minimal compared to today's standards, but the limitations of the technology at the time led Gerhard to be more inventive and imaginative with the tools at his disposal.



WHAT MAKES GERHARD'S WORK SPECIAL?

"Gerhard is a fascinating character," says Monty. "What he chose to record, how he used the technology he had available to change the sound, and how he then used it in the final version of a piece is always a wonderful process to investigate." As researchers, Monty and Sam not only listen to Gerhard's work, but also read letters written by or to Gerhard and those around him, looking for clues as to how and why Gerhard made the music he did.

Monty has been exploring how Gerhard would split his work into small sections and release them as 'library' pieces for purchase. Though this is a common practice today, Gerhard was one of the first serious composers to do this. Meanwhile, Sam has been investigating Gerhard's involvement in the music for *The Prisoner* in 1954, the first piece of theatre music in England to use electronics. As they explain, "He really was a pioneer!"

Despite creating music for film and theatre, Gerhard was also a composer of so-called 'serious' concert music. "Gerhard successfully fused a number of concepts drawn from the developing ideologies of electronic music at the time with his own ideas of what electronic music could and should be," says Monty. "This commitment to his personal vision resulted in the production of music unlike anything else in existence at the time." These sophisticated

ideas were very apparent in his work for film and television, helping to bring his novel compositions to a mainstream audience.

BRINGING A MODERNIST INTO OUR MODERN WORLD

Monty and Sam have painstakingly reconstructed a comprehensive open-access archive of Gerhard's work, to bring it to a new generation of listeners and composers. "His work was originally digitised in 2012, but technology moves fast, and those files and the associated database are now not compatible with our current technology," says Sam. This highlighted the importance of ensuring that, this time round, digitised files are created in a format that provides backwards compatibility.

As well as digitising all 610 tapes in the Roberto Gerhard Archive, Monty and Sam also processed the recordings of each tape to remove silence, clicks and unwanted noise found in the tapes, leaving just the electronic music. "We also spent considerable time transcribing interviews, radio broadcasts, recording sessions and so on," says Monty, who believes that gaining insight into Gerhard's character and background is essential to understanding his music. "We hope that composers will use the archive to not only listen to Gerhard's electronic music, but also to better understand his working process." This means that we can experience how Gerhard used different



PROFESSOR MONTY ADKINS

Professor of Experimental Electronic Music, University of Huddersfield, UK



DR SAM GILLIES

Postdoctoral Researcher, University of Huddersfield, UK

FIELD OF RESEARCH

Music Technology

RESEARCH PROJECT

Gerhard Revealed: Digitising the work of Roberto Gerhard, making it accessible to a contemporary audience

FUNDER

Arts and Humanities Research Council (AHRC)

inspirations, raw materials and manipulations of sound to end up with the finished product.

With all recordings digitised, Monty and Sam have constructed an accessible, online archive of Gerhard's work, so that everyone can enjoy his music. Why don't you explore the archives yourself? Visit www.heritagequay.org/rgda/roberto-gerhard to discover Gerhard's creations and experience the music of this pioneering artist.

ABOUT ELECTRONIC MUSIC

WHAT DEFINES ELECTRONIC MUSIC?

“Most fundamentally, electronic music utilises the flow of electrons, as opposed to natural resonances, to generate sound waves,” says Monty. “This means that electronic music allows for the creation of sounds that are not possible with traditional instrumental music.” This means that electronic music is difficult to classify as a ‘genre’, since it can incorporate such a vast range of different sounds and styles. Any possible sound that can be recorded or synthesised is fair game for inclusion in electronic music. “Electronic music can be made out of any sound. It can be about timbre, texture and strange harmonies that are impossible on instruments, or creating weird atmospheres or very deep physical sounds.”

HOW DO ELECTRONIC MUSIC COMPOSERS CREATE THEIR WORK?

“Electronic music is made and recorded directly onto a tape or, these days, a computer by the composer,” says Sam. “There are no intermediaries.” This differs from ‘traditional’ music, where composers write notes on paper or a screen – essentially creating a set of

‘instructions’ for the players. Electronic music bypasses this step completely, meaning the composer has full control over the finished product. “The composer of electronic music shapes every last sound, every last part, just like a sculptor or painter creates their work of art,” says Sam.

HOW HAS ELECTRONIC MUSIC COMPOSITION CHANGED OVER TIME?

“You can trace electronic music as far back as the Industrial Revolution, when electricity first began to be harnessed,” says Monty. “For instance, Thaddeus Cahill’s Telharmonium, patented in 1897, was an electrical organ that transmitted sound via telephone wires.” Since then, as electronic technology advanced, electronic music followed suit. “The use of tape machines for making experimental music really developed from the late 1940s and early 1950s,” says Sam. “This indicates how pioneering Gerhard was, having his own private recording studio by 1954.” The development of computers heralded a new era for creating electronic music, with endless possibilities now available for electronic composition.

HOW CAN YOU GET INVOLVED IN ELECTRONIC MUSIC?

“It has never been easier to work with electronic music!” says Monty. “You can download composition programmes such as Audacity or Reaper on almost any computer, and your phone can capture raw audio recordings of interesting sounds you find in the world.” There is a whole host of software, apps and sample libraries available that mean you can begin composing electronic music almost immediately!

Sam advises simply listening to a lot of music, including music that may not immediately be to your liking. “The stuff you do not like is in some ways more meaningful than the stuff you do,” he says. “Learn to express why you do not like it and think about whether you can find interesting features within it.” This self-critical process can help inform decisions around composition – including aspects that people may enjoy, or some that could challenge existing preconceptions.

EXPLORE CAREERS IN ELECTRONIC MUSIC

- There are a wide range of careers available in electronic music. For example, creative industries such as film, radio, broadcasting and production all use electronic music.
- Careers in Music has blogs and articles about all aspects of working in the music industry: www.careersinmusic.com
- Prospects provides information about careers in music production, including the type of work you might do and the salary you can expect: www.prospects.ac.uk/job-profiles/music-producer
- This blog post explores a pathway for getting into electronic music production in a personable and relatable way: www.edmprod.com/5-stages-electronic-music-producer

PATHWAY FROM SCHOOL TO ELECTRONIC MUSIC

- Many universities and colleges offer courses in music production, studio recording and electronic music, all of which lend themselves to a career in the sector.
- Monty recommends learning about the historical and artistic context surrounding the emergence of electronic music. At school, this can translate into taking subjects such as English literature, history, drama, art and, of course, music.

HOW DID MONTY BECOME A MUSIC RESEARCHER AND COMPOSER?

HOW DOES YOUR PROFESSORIAL ROLE INFORM YOUR CREATIVE OUTPUTS?

First and foremost, I am a creative person. I make music and have worked as a sound designer. Being able to teach this to students is very inspiring. They always have new ideas and suggest I listen to new music. Additionally, the research I do often feeds directly into my creative work. Even the work on Gerhard, which is more 'historical', has made me think about how we use the technology we have and about creative ways of working with sound.

WHY DID YOU TRANSITION FROM STUDYING FRENCH MEDIEVAL AND

ITALIAN RENAISSANCE MUSIC TO MORE MODERN ELECTRONIC MUSIC?

I have always been fascinated by very early music and very new music. Early music is unusual in terms of harmony, form and old instruments. A lot of these different ways of making music 500-800 years ago can be reinterpreted and applied to electronic music in a creative way.

WHAT IS YOUR FAVOURITE FACT ABOUT GERHARD?

There are wonderful letters about Gerhard and his wife, Poldi, recording the audio of things rolling down the stairs in the middle of the night when it was very quiet. In addition, listening to Gerhard and Poldi record piano

and accordion sounds together shows a really human side to them both.

WHAT DO YOU ENJOY DOING IN YOUR FREE TIME?

When I have free time, I like cycling and spending time with my partner – she is also artistic, so I end up making things with her too. Other than that, I am always listening to music and composing. Even when I take a break from work, I am still thinking about music.

HOW DID SAM BECOME A MUSIC RESEARCHER AND COMPOSER?

HOW DOES YOUR ROLE AS A RESEARCHER COMPLEMENT YOUR COMPOSITION AND PERFORMANCE WORK?

They are different but related, with each informing the other. Both are creative in their own way, with research allowing me to focus on exploring narratives and stories that exist around electronic music, and composition exploring more fundamental ideas of what music can be and what it can express. I see them as fundamentally linked.

HOW DID YOUR UNDERGRADUATE DEGREES LEAD TO YOUR CURRENT POSITION?

I first studied an arts degree in communication studies, which was a good place to learn more generally about the variety of artistic concerns throughout the 20th century and to hone my skills in writing and research. When I pursued a degree in music composition a few years later, I could easily translate this experience into my musical practice.

WHAT DO YOU ENJOY DOING IN YOUR FREE TIME?

I'm a fan of professional wrestling and have found that a firm understanding of kayfabe – the portrayal of staged wrestling events as 'real' – is helpful in making sense of the music world. I listen to a lot of music outside of work hours, trawling through different albums to try and find weird and interesting ideas. I don't think you choose a life in music if you lack an insatiable interest in it!

MONTY AND SAM'S TOP TIPS

- 01** Learn to love to read. Many of the best ideas are not communicable any other way, and if you do not learn to love diving into ideas expressed in written form, then some of the most important concepts of our time will not reach you.
- 02** Learn to be inquisitive and do not accept the goal-oriented status quo. Do things your way and have the confidence to give anything a go. If it does not work, the experience may still lead to something you would never have done if you had not tried.
- 03** Take time to experiment and find out what it is about music, technology and being creative that really drives you. That way you will have an original voice and something to contribute that is truly you.

WHEN CHIPS MEET PAPER: THE EXCITING WORLD OF PRINTABLE ELECTRONICS

ELECTRONICS ARE ENTERING A NEW PHASE. AT THE **UNIVERSITY OF SURREY** IN THE UK, **DR RADU SPOREA** IS LEADING A TEAM INVESTIGATING HOW TO 'PRINT' CIRCUITS ONTO PAPER, CREATING DEVICES THAT COMBINE THE PHYSICAL AND DIGITAL WORLDS. THIS IS OPENING NEW POSSIBILITIES FOR FLEXIBLE, INTEGRATED ELECTRONICS, WHILE SIMULTANEOUSLY PROMOTING ECONOMICAL AND ENVIRONMENTAL BENEFITS

TALK LIKE AN ELECTRONICS ENGINEER

CIRCUIT - in electronics, a route that allows electricity to flow from one point to another, through one or more electrical or electronic components

CONDUCTOR - a material that can carry electrical charge when voltage is applied

INSULATOR - a material that cannot carry electrical charge

SEMICONDUCTOR - a material with conductivity that can be modified while in operation, by interactions with heat, light or electric fields. Semiconductors serve as the basis of electronic devices

SILICON CHIP - a fingernail-sized object composed of semiconductor, conductor and insulator materials that holds miniaturised electronic circuits. These circuits are capable of performing operations like signal amplification, logic tasks and storing information

SUBSTRATE - the underlying substance that something of interest is attached to

The age of electronics is flourishing. The phone in your pocket is thousands of times more complex than the Apollo Guidance Computer that put the first human on the moon. We live in a world surrounded by incredibly high-performing technologies that make our lives easier and more connected.

However, there is a catch. Our rapidly-evolving electrical and electronic machines require a lot of energy and materials to make. Metals such as cobalt, copper, neodymium and indium must be mined from the Earth, a process that often has large environmental and ethical costs. Then, after these products come to the end of their life, there is the problem of their disposal. Electronics are difficult to recycle and can leak toxic substances if not disposed of correctly. Solutions are therefore needed to make electronics less resource-intensive.

NEW TYPES OF ELECTRONICS

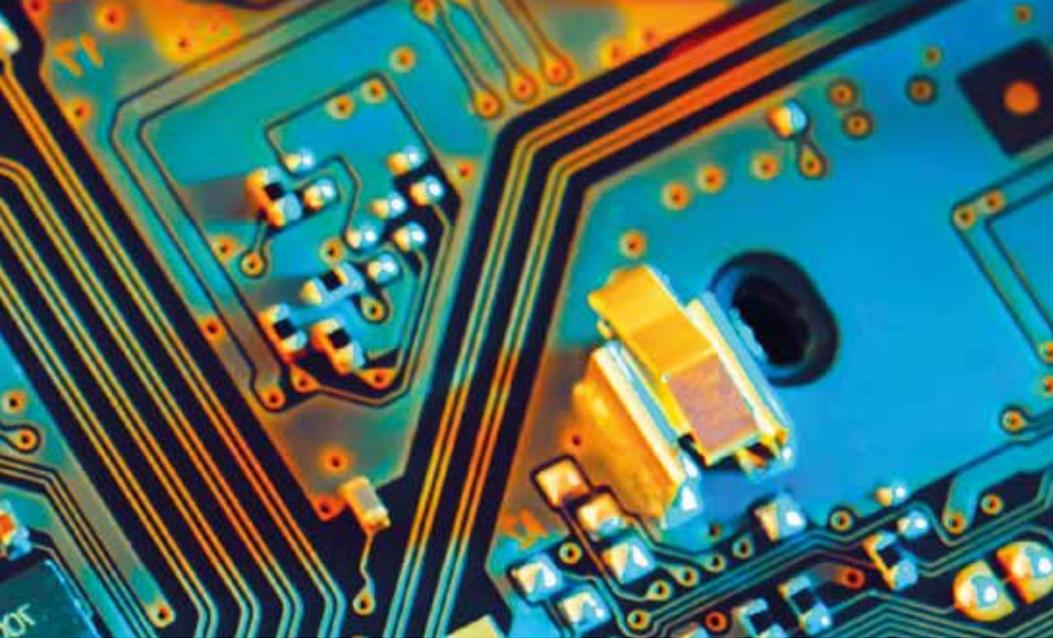
"The silicon chips we use in our phones, computers, cars and anything else electronic are rigid, fast and comparatively expensive to make," says Dr Radu Sporea, Senior Lecturer in Electronic Engineering at the University of Surrey. "However, it is possible to make circuits with basic functions with much cheaper technologies and substrates." While comparatively slow, these electronics can be 'printed' onto cheap materials, such as paper or

plastic, creating a whole range of possibilities for flexible electronics.

These printable electronics could fulfil functions that do not require standard high-performing silicon chips. For instance, when measuring environmental variables that change slowly, such as temperature, air pollutants or a person's pulse, it does not matter if the electronics are also slow. "Making these printed circuits uses far less energy, fewer harmful materials and much cheaper equipment," says Radu. "They can also be made to be flexible, transparent and extremely large, if needed."

THE PRINTING PROCESS

So, how can electronics be 'printed'? "The process is more similar to printing magazines than it is to producing conventional silicon chips," says Radu. "Layer by layer, the constituent parts of the electronic devices are stamped, etched or printed onto a continuous roll of eco-friendly plastic or paper that is then cut into individual chips." The 'inks' used by these printers are specially formulated to have conductor, insulator or semiconductor properties. Printing different combinations of these inks can build electronic components from the ground up, as well as the wires that connect them, enabling functional circuits to be printed directly on low-cost substrates.



DR RADU SPOREA

Advanced Technology Institute,
Department of Electrical and Electronic
Engineering, University of Surrey, UK

FIELD OF RESEARCH

Electronic Engineering

RESEARCH PROJECT

Creating printable electronics with
sensory functionality, to be used in
a range of innovative applications

FUNDER

Engineering and Physical Sciences
Research Council (EPSRC)

“A lot of science and engineering goes into getting these components right,” says Radu. “From the ink properties to the alignment of the printed features, everything is carefully researched.” There is still a lot to learn in this process. Over time, Radu believes these printed applications could be made even thinner, with boosted performance and a greater range of possible functions.

PLASTIC VS PAPER

“Plastic is a convenient substrate to print onto and can sometimes be biodegradable, but paper is also attractive as a more ecological alternative,” says Radu. “The main issue with paper is that, while plastic sheets can be made smooth at the microscopic level, paper is made of relatively large fibres meshed together.” This is a problem, as the ‘landscape’ that the components are printed onto will be very non-uniform, full of bumps and ridges, meaning it

can be difficult to ensure the reliability of the electronics created.

Radu’s team has developed an ingenious way of overcoming this problem. “In any electronic circuit, contact between a metal and a semiconductor creates an energy barrier that is normally surmounted by electrical charges,” he explains. “In contrast with most electronics design, we use this barrier deliberately in our work, as a way of regulating how much current can flow. This ensures that components that end up being not quite identical, due to variations in the manufacturing or substrate properties, can still have the same behaviour.” Even though this makes the circuit “embarrassingly slow” compared to standard circuits in silicon chips, this is not a problem for the applications such flexible circuits are designed for, in which a regular and predictable current is far more important than speedy processing power.

APPLICATIONS OF PRINTED ELECTRONICS

NEXT GENERATION PAPER

Radu’s group has teamed up with other researchers to put these ideas into practice. “Next Generation Paper is an interdisciplinary project to design a meaningful way to add digital information to a paper book,” says Radu. Unlike an e-book, which is a digital book viewed on an electronic screen, an augmented book, or a-book, is a paper book linked with additional digital content.

“We chose to demonstrate Next Generation Paper on a travel guide, as it embodies both the benefits and shortcomings of paper books.” Travel guides have the look and feel of books that many people like, can easily be carried around, are robust and do not depend

on an internet connection. However, their information becomes outdated over time and they cannot display audio or visual information.

“For our augmented travel guide, we used simple electronics to enable the book to ‘know’ what page is being read by printing light sensors on every page,” explains Radu. “By connecting these to a simple decision circuit and a transmitter, the book relays this information to a nearby device such as a smartphone, which then displays relevant content.” This might be videos of destinations, up-to-date opening times for a venue or recent reviews of an attraction. “We have kept the interaction with the book as natural as possible, so as not to detract from the reading experience and the ‘bookness’ of the book,” he says.

THE MAGIC BOOKMARK

As an alternative to light sensors and electronics within the book, Radu’s team has developed a ‘magic bookmark’ that, when placed on a page, reads an invisible code printed on the page and sends this to a nearby smart device, which will then access related digital content. “The idea is to use a natural gesture – the handling of the bookmark – rather than the fairly widespread action of pointing a smartphone camera at a page, which would interrupt the reading experience,” says Radu.

The team is bringing this bookmark to life with a unique new tome, the Climate Domesday Book. This book will compile contributions from scientists and artists from around the world, exploring ideas about climate change, energy use and the future of our planet. “The book has been designed to be a hybrid printed-digital format,” says Radu. “The magic bookmark will be used to seamlessly connect up-to-date multimedia content with the printed information.”

These projects demonstrate just a few of the potential applications for flexible printed electronics, highlighting how Radu and his team are developing technology that will advance the field of electronic engineering.

ABOUT ELECTRONIC ENGINEERING

Electronic engineering involves the design and construction of circuits and electronic devices. These skills can be applied across a very diverse range of sub-disciplines. Radu explains more about the field:

As we've found in our projects, no single engineering discipline is sufficient for truly interesting breakthroughs. Our printable electronics projects require an understanding of electricity, semiconductors, device physics, maths, computer modelling, fluid dynamics, mechanics and chemistry, along with analogue and digital design, which is why we work in a

team. In the Next Generation Paper project, the required disciplines widened even further, to include designers, graphics artists, anthropologists and business experts. This project is truly multidisciplinary and extremely rewarding.

The world is changing rapidly and so are the skills needed for engineering. Core skills to manage these changes include discipline, problem solving, tenacity, confidence and planning. A degree in electronic engineering prepares you to be agile and adaptable to the inevitable changes that will arise during your career.

Electronics engineers are needed in a wide range of areas. You could find yourself working in robotics, nanotechnology or sustainable energy generation, or contributing to efficient transportation, smart cities or personalised medicine.

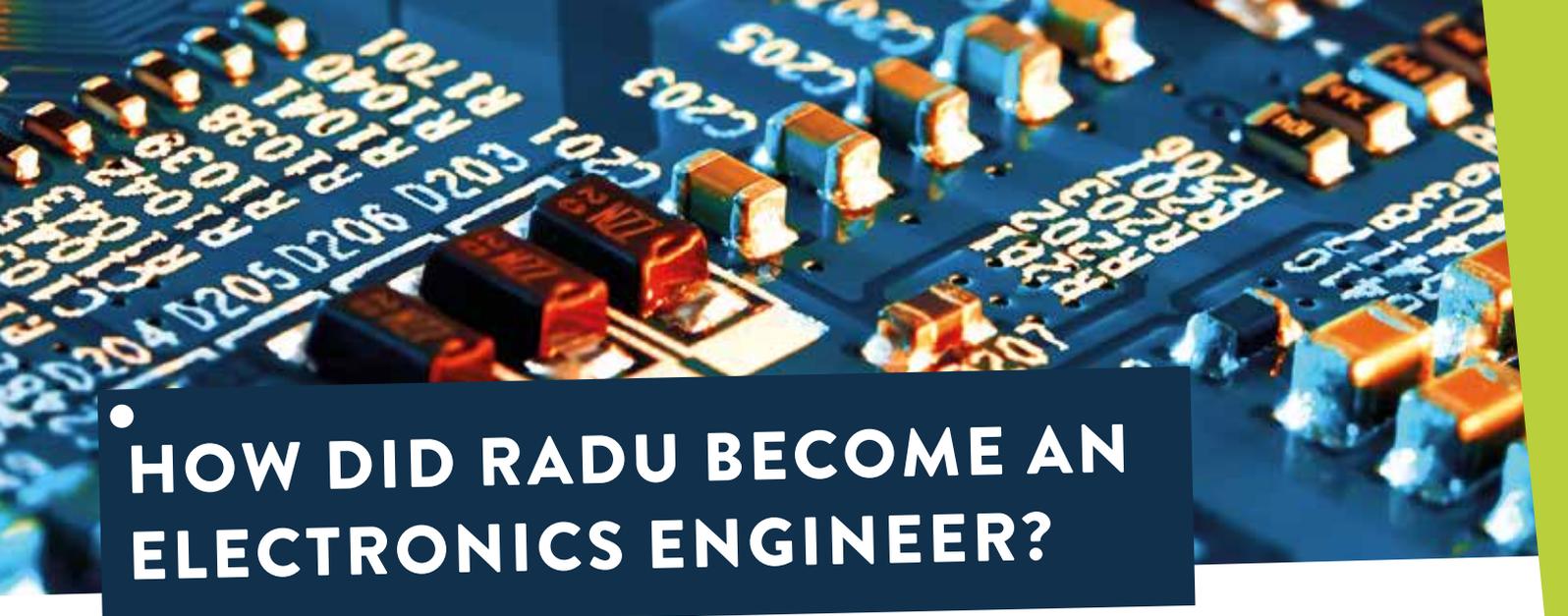
There is likely to be a shortage of engineers for years to come, leading to high demand for competent specialists. The skills that you will develop as an electronics engineer will allow you to continue to specialise or to adapt to other fields, within or outside engineering, throughout your life.

EXPLORE CAREERS IN ELECTRONIC ENGINEERING

- Radu's department at the University of Surrey runs free residential summer schools where students can sample different engineering disciplines: www.surrey.ac.uk/schools-colleges/sixth-form-colleges/residential-summer-schools
- Radu also runs summer research placements in his lab for sixth-form students, which have led to new scientific discoveries and academic publications: www.teamporea.info/future-member
- Radu recommends looking for opportunities to participate in research while still at school, to get a feel for what electronic engineering involves. Contact universities near you, or look for schemes such as SATRO Research Work Placements (www.satro.org.uk/research-work-placements) or Nuffield Research Placements (www.stem.org.uk/nuffield-research-placements)
- Electronics engineers are in high demand. Prospects provides information about the work you could do, the qualifications you will need and the salary you can expect as an electronics engineer: www.prospects.ac.uk/job-profiles/electronics-engineer

PATHWAY FROM SCHOOL TO ELECTRONIC ENGINEERING

- At school and university, courses in maths, science subjects and computing will be useful for pursuing a career in electronic engineering.
- Radu notes that there are many routes to specialisation within the field. Maths, physics and coding are useful skills in his research area of circuit design and development. Many electronic devices are optimised at the molecular level, which requires knowledge of chemistry and materials science. Complex maths and coding are often needed for robotics and artificial intelligence research.
- There are also many opportunities for electronic engineering careers in equipment design and facilities maintenance, requiring more practical electrical skills.
- Look for companies that offer apprenticeships or internships. These will allow you to learn about electronic engineering while being paid and gaining valuable practical experience.



HOW DID RADU BECOME AN ELECTRONICS ENGINEER?

WHAT WERE YOUR INTERESTS WHEN YOU WERE YOUNGER?

I was keen on building models with Lego and Meccano, but not that much into electronics. When I was six, my parents enrolled me in a computer class and I began to enjoy programming, which gradually changed into an interest in computer hardware and then chip design.

HOW DID YOU BENEFIT FROM WORKING IN INDUSTRY AS A STUDENT?

Halfway through my degree in computer systems engineering, I was looking for a summer job and one of my professors recommended me to the local branch of a Silicon Valley chip company. I ended up working in circuit layout and design, where I contributed to new inventions that are now used in commercial chip designs, which resulted in a US patent. I enjoyed the research element of the work, so decided to do a PhD.

WHAT IS YOUR WORKING LIFE LIKE?

I teach first and third year undergraduate electronics students and lead a small, but highly capable, team of researchers who are developing the next generation of efficient, flexible and printed electronics. I want to improve technology to drive a better quality of life. I am fortunate to work with dozens of exceptional researchers from around the world in pursuing this goal.

WHAT ARE SOME HIGHLIGHTS OF YOUR CAREER?

I have been awarded two national research fellowships, which confirm the importance of my research and the uniqueness of my team's approach. Awards for teaching have recognised my other great passion. Outside work, the births of my daughters reminded me to choose wisely about what to focus on and to consider what brings meaning in life.

WHAT IS NEXT FOR YOUR CAREER?

I am focusing on translating our research ideas into practical technologies that are economically viable, energy efficient and sustainable. I would love to see these concepts taken up by manufacturers, to help improve quality of life through ecologically-minded technologies.

WHY DO YOU ENJOY ENGAGING THE PUBLIC WITH ELECTRONIC ENGINEERING?

It's important to show the reality of research and engineering, and that the satisfaction of creating something useful greatly outweighs the challenges that must be overcome. Modern electronics are impenetrable, so we need to make them accessible. The slick appearance of a smartphone conveys very little of its nanoscale physical constituents. If you can't see what's inside, you can hardly be tempted to explore the wonders of electronics.

“IF YOU CAN'T SEE WHAT'S INSIDE, YOU CAN HARDLY BE TEMPTED TO EXPLORE THE WONDERS OF ELECTRONICS.”

On a personal level, I found public speaking exceptionally challenging early in life, so putting myself in these terrifying situations has helped my personal development. I still feel pressure whenever I speak in public, but I embrace it because I am confident in the importance of the interaction.

WHAT DO YOU ENJOY OUTSIDE OF WORK?

Spending time with my daughters is a top priority. I also play guitar – badly, but it brings me joy. And, I have an interest in travel, cars and photography, and I try to combine these whenever I visit research collaborators abroad.

RADU'S TOP TIPS

1. Don't hesitate to ask for help in achieving your ambitions.
2. Allow time for thinking. If you're busy all the time, it's difficult to link ideas to create something new.
3. Eat well and get enough sleep. Your focus and creativity will skyrocket.

UNDERSTANDING, DETECTING AND COMBATTING DEEPFAKES IN THE REAL WORLD

DR YU CHEN, BASED AT BINGHAMTON UNIVERSITY IN THE US, IS DEVELOPING A MEANS OF UNDERSTANDING AND DETECTING DEEPFAKES IN ONLINE VIDEO SYSTEMS. THE FINDINGS WILL HELP ADVANCE THE RESEARCH FRONTIER OF AUDIO AND VIDEO STREAMING DATA SECURITY

TALK LIKE AN ELECTRICAL AND COMPUTER ENGINEER

INTERNET OF THINGS – a system of interconnected computing devices, mechanical and digital machines, objects, animals or people

FREQUENCY – the number of waves, cycles, or vibrations by a body in motion that passes through a fixed point in a given period of time (typically 1 second). For example, 60 cycles in 1 second, resulting in 60 Hz

POWER DISTRIBUTION NETWORK – the distribution of electric power from the generating points to the final destination, made of components such as cables and transformers

NOMINAL FREQUENCY – the frequency specified for a device (usually 50Hz) for normal operation by the device's manufacturer or supplier

DEEPFAKE – superimposing, merging or replacing the likeness of an individual on a subject, and making it appear authentic and real

EDGE CAMERA RECORDING/ STORAGE – when a device, like a camera, stores recorded information directly on an inbuilt storage system rather than on an external storage device

BLOCKCHAIN – a shared, immutable ledger that facilitates the process of recording transactions and tracking assets across computers that are connected as a peer-to-peer network

PREVALENCE OF DEEPFAKES

The rapid growth of the internet in the 20th century has made it increasingly difficult to know what is true and what is false. Indeed, while conspiracy theories have existed for hundreds of years, online communities enable people to come together to share their theories, with each individual capable of bolstering the strength of the community's belief in what it deems to be true. One notable instance is the increased popularity of the notion that the Earth is flat – this is demonstrably false, but some people are convinced that our planet is a flat rectangle and not a sphere.

Deepfakes and deepfake attacks have only added to the misinformation that is readily available

online. Deepfakes are synthetic media in which existing audio, image or video is replaced with another person's voice or likeness.

Some of these deepfakes are so realistic that it appears as if the person has done or said what the video demonstrates. As the technology used to create deepfakes becomes more sophisticated, the ability to separate fact from fiction becomes increasingly difficult, which can cause significant problems around the world.

It is with this in mind that Dr Yu Chen, based at Binghamton University in the US, is engaged in a project focused on developing a means of understanding and detecting deepfakes in online video systems. The research project aims to help

neutralise the ability of these videos to mislead the public and cause friction between people and even countries.

There is a range of deepfake tools available, thereby enabling people to become anyone, from Elon Musk to Eminem, during video conversations. Almost anyone can use simple video manipulations with modified voices; so, instances of deepfake attacks are on the rise.

"Deepfake video 'attacks', in some public scenarios, have raised more concerns. For instance, in 2017, the start-up Lyrebird posted short audio clips simulating the then US presidential candidates Obama, Trump and Clinton discussing the company's technology with admiration," explains Yu. "Researchers have pointed out that disinformation may cause disturbance in our society and ruin the foundation of trust. More recently, on 17th March 2022, a deepfake video was posted on social media showing Ukraine's President Zelensky calling for his country's soldiers to surrender."

DETECTING DEEPFAKE ATTACKS

The Electrical Network Frequency (ENF) is an instantaneous frequency in power distribution networks that varies across its nominal frequency of 50/60 Hz, based on power supply and demand from consumers. It has been observed that the surveillance feed contains traces of ENF in both audio and video recordings, so if Yu and his team



DR YU CHEN

Professor, Department of Electrical and
Computer Engineering
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Cybersecurity, Binghamton University,
State University of New York, USA

FIELDS OF RESEARCH

Security, Trust and Privacy in Edge
Computing and Internet of Things (IoT),
Smart Cities

RESEARCH

Developing a means of understanding
and detecting deepfakes in online video
systems. The findings will ensure increased
reliability in what is presented as the truth

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those of the authors and should not be
interpreted as necessarily representing
the official policies or endorsements,
either expressed or implied, of the US
Air Force.

approaches to theoretically prove the effectiveness
and robustness of their approach. Ultimately, Yu's
research will help to combat the rise of 'fake news'
in an era where people doubt the veracity of that
which is true and believe false information.

can detect these traces, they can determine
whether the video and audio are real or fake.

"In this research, ENF signals are extracted
from video/audio recordings generated by edge
cameras connected to the power grid. The
authenticity of ENF signals is validated using
signal traces collected at multiple locations within
the same power grid," says Yu. "Next, a dynamic
cross-correlation coefficient is adopted that
verifies the authenticity of the ENF estimate
with a parallel ground truth ENF estimate from
the main power grid."

The team has worked on building and testing a
proof-of-concept prototype using real-world
scenarios and the experimental results have
been analysed to verify the effectiveness and
correctness of the proposed detection scheme.

WHAT MAKES YU'S METHOD OF DEEPPAKE DETECTION NOVEL?

It is a continuous battle between the
development of deepfake technology and the
development of deepfake detection methods.
The countermeasures and mitigation tools
available for detection are still in their infancy.
Often, it is enough to catch inconsistencies in
audio and video streaming (AVS), such as subtle
facial expressions that are not realistic, using
machine learning.

Artificial intelligence (AI) can be employed to
make fake audio and video sound and look even
more real. "Instead of engaging in the endless
AI 'arms race' where we fight fire with fire, our
research approaches the problem from a different
standpoint," explains Yu. "Our method delivers a
disruptive technology that enables the ultimate
victory in the battle against deepfake attacks."

Apart from the obvious benefits of being able
to distinguish between what is real and what
is fake, the success of the research will also
advance the research frontier of AVS data
security. "The results from our studies will
enable more novel Internet of Video Things
(IoVT) and edge computing-based applications
to be developed," says Yu. "This is essential for
mission-critical delay-sensitive applications,
where fake video inputs will cause disastrous
consequences, including kinetic military
action, law enforcement, civil protection,
disaster relief, social movements, business
teleconferences and many others."

So far, the team has validated the correctness
and effectiveness of the ENF-based detection
algorithms for two scenarios. One is a proof-
of-concept prototype tested with deepfaked
audio and video authentication in an online video
conferencing setup and verifies the feasibility of
the system called DeFakePro.

The other is a Lightweight Environmental
Fingerprint Consensus (LEFC)-based
detection of compromised smart cameras in
edge surveillance systems. By integrating a
novel blockchain-based consensus protocol,
the DeFakePro and LEFC schemes can detect
deepfaked video/audio inputs in real-time.

WHAT ARE THE NEXT STEPS FOR THE RESEARCH?

The team is engaged in multiple ongoing tasks,
including the detection of deepfaked video, audio
and photos on social media or other sites. In
addition, they are working on developing a deeper
understanding of the robustness of the proposed
methods for use in forensics. Yu and his team
also want to develop information theory-based

ABOUT ELECTRICAL AND COMPUTER ENGINEERING

As Yu's research shows, the field of electrical and computer engineering can lead to the development of technologies that make the world a better place. Computers and computing technologies are developing at such a rate that there will always be new challenges arising from one day to the next, so scientists and engineers working within the field will always have something to do. You can take your career in so many different directions, which means that it is up to you what pathway you choose to take after you have obtained your degree – or you can instead decide to take a work placement that will give you real-world experience.

WHAT DOES YU FIND REWARDING ABOUT RESEARCH IN HIS FIELD?

Yu reveals that it is hugely satisfying to find, design and invent new solutions to tackle cutting-

edge challenges. "I love working to help humans and society move forward," he explains. "I find that helping society enter into a safer, more secure and more convenient mode of living in the future is what inspires me daily."

WHAT CAN THE NEXT GENERATION OF ELECTRICAL AND COMPUTER ENGINEERS EXPECT TO BE WORKING ON IN THE FUTURE?

As intelligent information and communication technologies are continuously and pervasively woven into the daily operations of the world, the next generation of electrical and computer engineers will become increasingly indispensable. "I envisage the next generation of electrical and computer engineers will design, implement, manufacture, test, maintain and secure the critical infrastructures which form the solid

"I LOVE WORKING TO HELP HUMANS AND SOCIETY MOVE FORWARD."

foundation of modern human society," says Yu.

If you want to become part of an increasingly exciting field that will only become more important in the future then electrical and computer engineering might just be the research field for you!

EXPLORE CAREERS IN ELECTRICAL AND COMPUTER ENGINEERING

- The Institution of Engineering and Technology has a student hub which contains loads of useful information: www.theiet.org/career/routes-to-engineering/student-hub/
- Electrical Careers is a resource focused on the industry which will show you the options available to you: www.electricalcareers.co.uk
- According to Payscale, the average salary in the US for Electrical Engineers is \$79,163 and \$87,753 for Computer Engineers.

PATHWAY FROM SCHOOL TO ELECTRICAL AND COMPUTER ENGINEERING

- Yu suggests that students wishing to pursue a career in the field should focus on taking mathematics, physics and programming – if your school offers it.
- Two or three A levels, or equivalent, for a degree.
- You could do a Level 4 and 5 Higher National Diploma in Electrical and Electronic Engineering at college before looking for work. To take this route, you'll need one or two A levels, a Level 3 diploma or relevant experience. You can find more information on Prospects: www.prospects.ac.uk/careers-advice/what-can-i-do-with-my-degree/electrical-and-electronic-engineering or on the UK national careers website here: nationalcareers.service.gov.uk/job-profiles/electrical-engineer

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MEET DEERAJ



DEERAJ NAGOTHU

PhD Student

Electrical and Computer Engineering

As a group, we focus on enhancing the IoT/edge computing devices with modern technologies like blockchain and artificial intelligence (AI).

My role as a researcher is focused on secure authentication of media transmissions and preserving information integrity against audio and visual layer attacks in edge devices. Frame forgeries enhanced by AI can significantly alter the perception of events by creating false realities and threatening our information security and privacy. My work aims to create a solution to distinguish the fake from the original using a unique environmental fingerprint technique.

A typical day consists of reading new publications to widen the scope of our research,

designing and conducting experiments with new algorithms, and measuring how it fares against the media forgeries, which typically involves coding in multiple languages for the development and deployment stages.

While pursuing my master's degree, I started my academic research on Network Computer Security.

My research aimed to study the network attacks that are launched through web browsing, so I created a Honeypot (Decoy) system to browse unsecured networks and discover zero-day exploits. I had also developed an interest in modern computer vision applications using Deep Learning. I realised how easy it could be to create a media forgery attack and deploy it in networked devices like surveillance systems that solely depend on their visual input for security. This led to developing my thesis on securing the multimedia in edge devices using techniques that are extremely hard for a Deep Learning model to replicate and forge.

I have interests in landscape and astrophotography, which is where my interests in images developed.

I have also been involved in many robotics projects during my bachelor's

degree. Recently, I have spent some personal time developing a mini self-driving car using computer vision.

Dr A.P.J Abdul Kalam, an aerospace scientist

and the 11th President of India, and my father are my inspirations, who taught me to value education and hard work in becoming an excellent scientist.

I love to explore new knowledge fields, constantly learning and teaching (which helps figure out the holes in my knowledge), working without getting distracted and, most importantly, being persistent.

I want to research cutting-edge technology in AI development and its secure integration into our environment, moving forward, leading to becoming a well-published writer in academic literature.

HOW DID YOU BECOME AN ELECTRICAL AND COMPUTER ENGINEER?

WHAT WERE YOUR INTERESTS WHEN YOU WERE GROWING UP?

I love history – reading allows me to live different lives and recognise what the most important things in my life are. I was also curious to figure out what happens inside machines. I disassembled my grandpa's TV when I was a kid, but when I tried to put it back together, I found there were a few small pieces leftover!

WHO OR WHAT INSPIRED YOU TO BECOME AN ENGINEER?

When I was a third-grade pupil in elementary school, a book that described how the Wright brothers invented, built and flew the world's first airplane opened my eyes to the amazing things that engineers can do.

WHAT ATTRIBUTES HAVE MADE YOU SUCCESSFUL AS AN ENGINEER?

I guess the most critical factors are maintaining curiosity and the capacity to pick up new knowledge and skills when needed.

HOW DO YOU TAKE A BREAK FROM YOUR WORK?

My main activity is reading history books, specifically the history of technology. I am particularly interested in the development of humans over time, and how we have evolved to make and do truly amazing things. Gardening also brings me a lot of pleasure – being close to nature has a calming effect and helps me to cope with the stress of working life!

WHAT ARE YOUR PROUDEST CAREER ACHIEVEMENTS SO FAR?

I am a firm believer that the proudest achievement is always the next milestone – this mindset keeps me on my toes and encourages me to keep moving forward with my research.

YU'S TOP TIPS

1. It is important to build a solid foundation of the fundamentals before pursuing more nuanced areas of enquiry.
2. Keep an open mind and do not be easily offended by differences of opinion – always be open to saying yes.
3. Do not work so hard that you burn yourself out; it is OK to play games or enjoy books outside of your research!

SHARING COMPUTATIONAL SKILLS TO ADDRESS NEGLECTED DISEASES IN LATIN AMERICA

TROPICAL DISEASES ARE A SIGNIFICANT SOURCE OF DEATHS ACROSS LATIN AMERICA, BUT, UNTIL RECENTLY, THERE HAS BEEN LITTLE INTEREST IN DEVELOPING DRUGS AND VACCINES TO TACKLE THEM. AS PART OF THE INNOVATIVE CABANA PROJECT, DR RODRIGO OCHOA FROM THE UNIVERSITY OF ANTIOQUIA, IN COLOMBIA, USES HIS SKILLS IN BIOCHEMISTRY AND BIOINFORMATICS TO DISCOVER NEW DRUGS AND IMPROVE THE STATUS OF BIOCHEMICAL RESEARCH IN LATIN AMERICA

TALK LIKE A CHEMICAL SCIENTIST

BIOINFORMATICS – using computational tools to understand large amounts of biological data

NEGLECTED TROPICAL DISEASES – a group of around 20 diseases which affect large numbers of people in tropical regions of the world, but which have received little attention in terms of treatment and prevention

LEISHMANIASIS – an infection caused by the Leishmania parasite

PEPTIDES – short chains of amino acids, which are the molecular building blocks of proteins

RECEPTOR PROMISCUITY – a feature of some proteins that enables them to bind to lots of different molecules

The World Health Organization estimates that over 1.7 billion people, mainly in developing countries, are at risk of neglected tropical diseases (NTDs). NTDs, such as leishmaniasis and leprosy, cause over 200,000 deaths and millions of disabilities each year. Despite this, treatments either do not exist for many NTDs, or are too expensive to be deployed on a large scale. These diseases are neglected because they are not profitable for pharmaceutical companies to invest in, and the people whom they affect tend to be the poorest and most vulnerable in society, who have the least political voice. Additionally, developing countries, which these diseases primarily affect, often lack the capacity to carry out their own research to find new treatments and vaccines.

CABANA (Capacity building for bioinformatics in Latin America) is an international research project funded by the UK's Official Development Assistance Budget. Focusing on infectious diseases, as well as biodiversity and food security, CABANA supports scientists in Latin America to use bioinformatics methods to solve societal problems. Building these capabilities is crucial to enable Latin American countries to conduct

research to find new treatments and vaccines for NTDs. CABANA is a collaboration between the European Bioinformatics Institute (EMBL-EBI) in the UK, and nine universities and research organisations spread across Latin America. As Dr Rodrigo Ochoa explains, the aim of CABANA is to, "provide connections with top research labs in Europe and Latin America, improving the competitiveness of the trainees and their research centres."

As part of his PhD in Chemical Sciences at the University of Antioquia, Colombia, Rodrigo participated in a six-month placement at EMBL-EBI, where he used structural bioinformatics and biophysics simulations to design peptides that can be used as potential vaccines for NTDs.

WHAT ARE PEPTIDES AND WHY ARE THEY IMPORTANT TO STUDY?

Peptides are short chains of amino acids that make up proteins. Proteins are the molecules that carry out most of the biological functions within our cells. Most drugs work by altering the ability of specific proteins to bind to other molecules and carry out their biological functions. Rodrigo studies the way in which proteins bind to each other. This process of



binding can be compared to a key fitting into a lock. Most proteins are designed to bind to a specific type of molecule, just as a key is made to fit into a specific lock. However, in a similar way to how a master key can unlock several different locks, some proteins can adapt and are able to bind to lots of different molecules. The reasons for this receptor promiscuity are not fully understood, so Rodrigo applies computational methods to understand how and why this can happen. Some of these proteins are involved in the immune system and are potential targets for treating NTDs.

HOW DOES RODRIGO CONDUCT HIS RESEARCH?

The computational methods Rodrigo uses involve the analysis of protein structures, as well as the simulation of protein interactions, in order to assess how small adjustments to the protein, or the binding partner, can impact their 'connection'. Simulating protein interactions is crucial to understand the mechanism of the proteins and the molecules they interact with, from a molecular perspective. By repeating this process millions of times, he can understand which parts of the proteins are the most important in controlling their ability to bind to different molecules. This enables the design of new drugs, made from peptides, that can specifically target these areas to deliver medical benefits.

Running these kinds of analyses presents certain challenges depending on the organism being studied. In the case of NTDs, information about the molecular structure of

proteins is scarce, which is why these diseases are considered 'neglected'. Like many other researchers in the field, Rodrigo relies on computational methodologies to infer these structures; a mixture of evolutionary information and data science enable him to fill in the knowledge gaps.

WHAT SUCCESS HAS RODRIGO HAD?

So far, Rodrigo's research has identified multiple molecules with potential therapeutic effects. These have been tested in laboratory-grown cells with positive results, and one of them has recently been patented by the Colombian government. Rodrigo and his collaborators have also developed a method to design variants in peptides as a potential method for creating more personalised vaccines. All the findings are currently in experimental and optimisation phases that are expected to move forward into viable products to tackle problems that concern the Latin American community.

HOW HAS RODRIGO SHARED HIS WORK WITH OTHER RESEARCHERS?

The main way in which scientific research is shared is through the publication of scientific papers, which explain how the research was carried out, and what the useful findings were. Along with his colleagues at the University of Antioquia and EMBL-EBI, Rodrigo has published 12 papers describing his research into peptides and NTDs. As part of his involvement in CABANA, Rodrigo also helped to organise a workshop to share the bioinformatics skills he learned on his EBI placement with other



DR RODRIGO OCHOA

Currently: Postdoctoral Research Fellow, Boehringer Ingelheim, Germany



FIELD OF RESEARCH

Chemical Sciences



PHD RESEARCH PROJECT

Using computational methods to develop new drugs and vaccines for neglected tropical diseases



FUNDERS

University of Antioquia, MinCiencias, The Max Planck Society, UKRI-BBSRC [grant no. BB/P027849/1], European Molecular Biology Laboratory

researchers in Latin America. This involved bringing together 25 early career researchers from 11 countries for a four-day workshop in Colombia, where they had a chance to learn new skills and form connections with other researchers in the field of bioinformatics and NTDs.

The CABANA project has also enabled Rodrigo to meet and collaborate with other researchers who share his interests. One research project that focused on modelling and testing possible inhibitors of parasite's proteins, with the aim of disease control, was led by Rodrigo and conducted between researchers of three different Latin American countries. This was a wonderful opportunity to share knowledge and unite efforts towards solving issues on communicable diseases affecting the region.

Projects such as CABANA – and Rodrigo's valuable contribution to it – show the importance of collaboration between developed and developing countries in creating the capacity for the latter to conduct their own research, not just in bioinformatics but in all branches of science.

ABOUT CHEMICAL SCIENCES

Chemical sciences is a broad field encompassing many aspects of chemical research. One of the largest areas of research is biochemistry, which is the study of the chemistry within living organisms. The behaviour and health of organisms is, ultimately, controlled by the chemical processes that occur inside and outside the cells, so biochemistry is crucial to understanding disease and finding new treatments and vaccines. There are both lab-based and computational ways of studying biochemistry, and the two complement each other very well. Modern-day biochemistry requires many more computational skills than it has in the past, and the area of bioinformatics is likely to keep growing.

WHAT DOES MODERN BIOCHEMISTRY LOOK LIKE?

The core of biochemistry is analysing the chemical composition of the molecules that make up cells and conducting experiments to see how cells are affected by changing their

composition, such as by applying drugs to try to correct disease.

Modern biochemistry has been driven by major advances in technology over the past 50 years, which allow us to measure and control the molecules within cells with ever increasing degrees of accuracy. Another major technological advance is the application of computing power to process very large amounts of data and look for patterns that could never be found by human researchers. This is the field of bioinformatics, which is a combination of computer science, statistics and biochemistry, and is one of the fastest growing fields within the life sciences. Computing power has also been used to conduct experiments that would be far too technically challenging, or time consuming, to conduct in the lab. Researchers can model complex molecules such as proteins on a computer and see what effect the millions of possible chemical variations have on their structure and function. They can then use this

information to identify candidate molecules, which could be tested as drugs to target these proteins.

AN EXCITING AND RAPIDLY CHANGING FIELD

Advances in computer power are constantly changing the limits of what is possible in bioinformatics and biochemistry. New projects such as AlphaFold, an artificial intelligence programme, take advantage of the latest techniques in computer science to search for solutions to longstanding biochemical questions. There is a real need to take these techniques from the established labs where they were developed, and apply them to problems affecting the developing world, where resources are much less available. This provides many opportunities for researchers at all stages of their careers, including their first steps on the career ladder, to make a difference to international problems that are currently neglected.

EXPLORE CAREERS IN CHEMICAL SCIENCES

- The Royal Society of Chemistry has an excellent careers section on its website. Find out more about what a career as a chemical scientist could offer you: edu.rsc.org/future-in-chemistry/career-options
- The CABANA project has several online courses teaching students about various aspects of bioinformatics: www.cabana.online
- Explore the work of The European Bioinformatics Institute (EMBL-EBI): www.ebi.ac.uk
- According to Payscale.com, the average salary for a bioinformatics scientist in the UK is £40,000: www.payscale.com/research/UK/Job=Bioinformatics_Scientist/Salary
- According to Erieri.com, the average salary for a bioinformatics scientist in Colombia is COP 50,000,000: www.erieri.com/salary/job/bioinformatics-scientist/colombia/bogota

PATHWAY FROM SCHOOL TO CHEMICAL SCIENCES

- Chemistry and biology are the core subjects that are important to study at school.
- At university, biochemistry and molecular biology provide the basic knowledge that is needed to understand the types of problems Rodrigo is working on.
- Some form of training in statistics and programming is very valuable as computational methods are heavily used in most areas of bioinformatics and chemical sciences today.



HOW DID RODRIGO BECOME A CHEMICAL SCIENTIST?

WHAT WERE YOUR INTERESTS WHEN YOU WERE GROWING UP?

My curiosity has always driven me to try to understand fundamental questions with a practical perspective. In particular, the field of computer science and programming always fascinated me and caught my attention, especially when applied to non-conventional topics like biology and chemistry. This is why I pursued a career in bioengineering and moved into the fields of bio- and chemo-informatics.

WHO OR WHAT INSPIRED YOU TO BECOME A SCIENTIST?

As a Latin American, it is not very common

to hear about scientists and their impact. When I started to study engineering, I found a wonderful opportunity to combine my career skills to provide new tools for scientists and, at the same time, try to answer those questions by myself with hybrid approaches using molecular information and efficient algorithms.

WHAT ARE YOUR PROUDEST CAREER ACHIEVEMENTS SO FAR?

During my PhD, I had the chance to publish multiple tools and advancements in the design of peptides and molecules with therapeutic purposes, especially in cases focused on

treating leishmaniasis, a parasitic disease affecting millions of people. Any effort in that direction is a big personal and professional achievement for me.

NOW THAT YOU HAVE COMPLETED YOUR PHD, WHAT ARE YOUR AIMS FOR THE FUTURE?

Having recently started a postdoctoral position at the pharmaceutical company Boehringer Ingelheim, in Germany, my aim is to work with the computational chemistry team to develop new tools that will accelerate the development of new drugs for multiple purposes.

RODRIGO'S TOP TIPS

- 01** You must be willing to get frustrated and persevere. Scientific research rarely happens completely in the way that you planned.
- 02** Try to make lots of connections with different researchers in your field and don't be afraid to ask questions with a positive and critical attitude.

COULD COMPUTER PROGRAMS MATCH THE ABILITIES OF OUR BRAINS?

THE HUMAN BRAIN IS ONE OF THE MOST INTRICATE SYSTEMS IN NATURE. RECREATING ITS BEHAVIOUR USING COMPUTER PROGRAMS IS NO EASY TASK, BUT IT CAN BE DONE – BY USING ARTIFICIAL INTELLIGENCE HARDWARE THAT MIMICS THE DEEPLY COMPLEX NETWORKS OF NEURON CELLS IN OUR BRAINS. DR PAVEL BORISOV AND PROFESSOR SERGEY SAVEL'EV, AT LOUGHBOROUGH UNIVERSITY, UK, ARE EXPLORING HOW NEW ADVANCES IN TECHNOLOGY CAN HELP TO CREATE AN ARTIFICIAL BRAIN

TALK LIKE AN ARTIFICIAL INTELLIGENCE RESEARCHER

ARTIFICIAL INTELLIGENCE (AI) - systems that can take in data from their surroundings and use it to take action to achieve their goals, without any input from programmers

ARTIFICIAL NEURAL NETWORKS - computing systems inspired by biological networks of neurons and synapses which can mimic the behaviour of our brains

MEMRISTOR - a resistor that can remember how much electrical current has

flowed through it in the past. Memristors are promising new components of artificial neural network hardware

NEURONS - nerve cells in our brains that communicate with each other by exchanging electrical or chemical signals

SYNAPSES - links between neurons through which signals propagate

WEIGHT - a connection strength between artificial neurons

Our brains are incredibly good at handling large amounts of complex information and applying previously learnt information in new situations. This is important for tasks like recognising familiar faces in a crowd or understanding words spoken by people with unfamiliar voices.

Computer programs that can perform these actions as well as us are extremely useful, but very challenging to build. Computers may be far better than us at remembering numbers and solving calculations, but not all information can be represented by numbers. This means regular computer programs cannot carry out many tasks as well as we can.

"If we write a computer program to detect

a circle of a certain radius in the middle of a monitor, it will do it extremely fast," says Professor Sergey Savel'ev, a theoretical physicist at Loughborough University. He is working on understanding if a brain can be implemented on an electronic chipset. "But the program will become confused if the radius of the circle is different, if it isn't in the centre of the screen, or the image is noisy." To overcome this problem, scientists are now developing more advanced programs that can better mimic the processes occurring in our brains.

WHAT ARE NEURAL NETWORKS?

Your brain contains millions of neurons, which constantly talk to each other by exchanging signals across connections named 'synapses'. As

we learn new information, the neural networks in our brains can alter connection strengths between other neurons, allowing the system to deal with new information more effectively in the future.

Scientists have recreated these systems in computers, using artificial neural networks. "Biological neurons are connected by synapses, while artificial neurons are connected by 'weights'," says Dr Pavel Borisov, an experimental physicist and Sergey's colleague at Loughborough University. "These simulated neurons can deal with input and output signals from other neurons."

As these programs experience new data, new weights will be assigned within the neural networks, so the output signals of particular artificial neurons will be processed in slightly different ways. For example, a neural network could be trained to recognise cats by showing it thousands of pictures of cats. Once trained, the system can then work out whether new, unfamiliar images contain cats.

Yet, even as neural networks become more advanced, they are still not nearly as effective as our brains. They work by filtering useful information out of useless data, rather than reproducing human thinking ability in understanding concepts. After all, we do not need to see thousands of pictures of cats just to recognise one!

HOW CAN MEMRISTORS IMPROVE NEURAL NETWORKS?

Improving neural networks further will require more advanced physical hardware. One way forward is to develop circuits that can actively change themselves as they encounter new information, something made possible through devices called memristors. These are related to the electrical resistors you have probably learnt about in physics, but can change their resistance depending on how much current has flowed through them in the past. Essentially, this gives them a 'memory'.

"Memristors can be used to replace weights in the software algorithms, so instead of storing all those numbers in the program, we can use each memristor's electric resistance to represent that weight," says Pavel. "That way, we don't need a special memory or a processor to sum up all the weights." In their research, Pavel and Sergey explore the exciting possibilities presented by this technology.

WHAT HAS SERGEY DISCOVERED SO FAR?

As our eyes take in new visual information, they convert it into electrical signals, which pass into an area of the brain called the visual cortex. The brain encodes the information onto short electrical pulses called 'spikes', which are sent on to be processed by other neurons, allowing the network to alter its synapses in response to the new information.

To recreate this behaviour in artificial neural networks, Sergey and Pavel use two types of memristor. "Volatile memristors return to the same state when electric power is off, so they aren't memorising what they learnt," Sergey says. "However, they can transform information into a series of electrical spikes, allowing artificial neurons to communicate."

In contrast, non-volatile memristors retain their memory when turned off and have a resistance that depends on the intensity and polarity of voltage spikes, making them more effective as artificial synapses. Sergey is combining these two types of memristor to better mimic the real visual cortex. He develops models to simulate memristor devices and artificial neurons in neural networks, then collaborates with Pavel to experimentally create these thin film devices and perform numerical analysis on spiking neurons.

HOW IS PAVEL'S RESEARCH IMPROVING MEMRISTOR DEVICES?

Pavel is developing new memristor devices by using fabrication techniques that are applied inside a vacuum chamber. This involves bombarding a solid disc of material with argon ions (a gas plasma), turning the thin top layer of the disc to gas. This gas settles on a solid, flat, glass-like substrate, forming a film just 100-500 atoms thick. By mixing the argon gas with oxygen, Pavel's team has fabricated memristors featuring a thin, slightly conductive oxide film, sandwiched between two metal electrodes.

"To understand if our memristor is working, we apply different voltages between the electrodes and measure the resulting current," Pavel says. "A proper memristor should demonstrate very distinct electric resistance values when the applied voltage is, for example, increased and then decreased, and the resistance should depend on the way the voltage was changed in the past."

Through this approach, Pavel has developed niobium oxide and silicon oxide films which can produce and control fast current spikes, in a similar way to biological neurons. The next step will be to connect these compact memristors into an advanced, low-power neural network.

COULD THESE DISCOVERIES BE APPLIED IN REAL LIFE?

For Pavel, the hope is to create prototypes of compact devices which can run neural networks using multiple built-in physical memristor elements that can operate without needing online access to a web server or external power grid. "These could include medical sensors to monitor heart or breathing rhythms, or engineering sensors to monitor the safety of buildings," he says.

For Sergey, the ultimate goal is to create an artificial visual cortex. "This device will be able to learn by itself and won't require any additional training or programming," he says. "This will allow it to adjust its performance depending on conditions in its environment, such as light intensity and the velocity of nearby objects."

Such a system could be used in robots, drones and self-driving cars, helping them navigate unfamiliar environments while remaining in contact with a central control system. In the future, it could even lead to implants to restore the sight of visually impaired people, although this is still some way off.



DR PAVEL BORISOV

Senior Lecturer in Physics, Department of Physics, Loughborough University, UK

FIELD OF RESEARCH

Thin Film Devices

RESEARCH PROJECT

Developing thin films to act as memristors in modern neural networks

FUNDER

Engineering and Physical Sciences Research Council (EPSRC)



PROFESSOR SERGEY SAVEL'EV

Department of Physics, Loughborough University, UK

FIELD OF RESEARCH

Modelling Complex Systems

RESEARCH PROJECT

Developing neural networks which can mimic the brain's visual cortex

FUNDER

EPSRC

ABOUT ARTIFICIAL INTELLIGENCE

Artificial intelligence (AI) is a large family of techniques, including neural networks, which enables computers to solve problems independently of human programmers. AI takes in information about the world, which could be gathered using sensors or by monitoring a person's online activity, then extracts useful information from this data and acts on it.

AI can be used in a diverse array of tasks, from allowing automated vehicles to navigate to suggesting relevant adverts for online shoppers. As this is still a new technology, some people are worried that it could transform our lives in negative ways we cannot yet predict. But for researchers such as Pavel and Sergey, the opportunities presented by AI are incredibly exciting, and could be used to solve some of the world's most complex problems.

HOW DOES AI TIE IN WITH OTHER FIELDS OF RESEARCH?

As the potential applications of AI are so diverse, most fields of research can benefit

from, and contribute to, advances in AI.

For Sergey, the tools used by physicists for modelling complex systems can fertilise the development of a new generation of intelligent systems, while AI can help physicists to shed light on many unsolved problems in electromagnetism, hydrodynamics, condensed matter and quantum physics. For Pavel, developing high-performance memristors involves understanding of solid-state physics, material chemistry and neuroscience.

Due to this diversity, it is no surprise that many scientists working on developing AI technology are also fascinated by completely different fields. The ability to communicate and collaborate closely with researchers from other subjects is therefore an essential skill for any scientist working to further improve AI.

WILL COMPUTERS EVER BE ABLE TO REPLICATE THE HUMAN BRAIN?

As technology continues to advance,

people are concerned that AI could one day become even more powerful than our own brains, an idea widely explored in science fiction. Sergey and Pavel both believe this is unlikely.

Since every brain is unique and constantly evolving as it responds to new information, Pavel says there simply is no way to recreate this in computer code. "It's like replicating a thunderstorm; you can be close, but never exactly there," he says.

However, Sergey believes the human brain is not the only, or even the best, intelligent system that exists. "We can create intelligent systems with quite different thinking abilities to us, possibly outperforming us in some respects, while still being less efficient than us in other thinking abilities," he says. Artificially mimicking the brain's behaviour more closely could lead to breakthroughs in ways to treat mental health issues, again highlighting the diversity and importance of AI applications.

EXPLORE CAREERS IN ARTIFICIAL INTELLIGENCE

- With a career in AI, you could find yourself designing robotic systems, programming virtual assistants or protecting computers from cyber-attacks. Almost all companies use some form of AI these days, providing a world of career possibilities for those with the skills to design and programme them.
- This article from Infosec discusses careers available in the field of AI: resources.infosecinstitute.com/topic/ai-and-machine-learning-career-paths-trends-and-job-prospects
- Prospects provides information about careers in machine learning, a branch of AI: www.prospects.ac.uk/job-profiles/machine-learning-engineer.
- C3 AI is an AI software provider. Visit their website to explore the type of AI applications they develop and the careers available: www.c3.ai

PATHWAY FROM SCHOOL TO ARTIFICIAL INTELLIGENCE

- "Mathematics is the key subject needed in AI research and applications," says Sergey. Skills in computing are also essential.
- As AI can be applied to any field, take subjects depending on your interests. For example, biology-inspired AI systems require a knowledge of biology and neuroscience, while quantum AI systems require a background in physics and quantum engineering.

HOW DID PAVEL BECOME A PHYSICIST?

I grew up in a family of two engineers, and most of my relatives worked in engineering and manufacturing. That meant that anything related to physics and maths had a special appeal to me when I was at school. I was more interested in physics than computers when I was young, but the physics and technology of computer components were always interesting to me, and I also had a parallel interest in human biology. That's what fascinates me the most about neural networks – the overlap between electronic devices and the brains of living organisms.

Research into electronic devices that can act as a human brain intensified in 2008, when the experimental discovery of a memristor was reported. I remember reading that paper and thinking that this would be a huge field of research.

Previously, I have worked on magnetic materials that can be influenced by both magnetic and electric fields. My research was the first to demonstrate the electric switching of a pure magnetic effect, the so-called exchange bias. I also developed an innovative technique for measuring the magnetoelectric effect, and synthesised and studied thin films of magnetic materials which were previously only investigated as bulk crystals. In the field of memristor devices, I'm proud of our work on artificial neurons made from niobium oxide films. In the future, the hope is to expand our research on memristive devices towards larger neural networks and sensors, and to demonstrate them in practical experiments.

PAVEL'S TOP TIPS:

1. Follow where your curiosity leads you.
2. Develop strong resilience when dealing with difficult calculations or failed experiments. Without it, you may become disappointed and give up too early.

HOW DID SERGEY BECOME A PHYSICIST?

SERGEY'S TOP TIPS:

1. To love science and to be interested in your studies are two key ingredients.
2. To challenge yourself and others is also very important during your studies. In the end, solving problems nobody can solve will really motivate you in future.

My mother and father were both chemists, so I started to think about a career in research quite early on. One of my first motivations was to understand the physics of life and the brain, but I spent a long time working in the field of superconductivity. I was excited to return to the subject I was interested in as a teenager with a different level of understanding, and with the goal of emulating the brain using electronic devices.

I always liked interdisciplinary research that went beyond standard physics. Currently, I am collaborating with the Loughborough School of Sport, Exercise and Health Sciences, developing new models to understand brain images. I like to use my mathematical skills in new fields of study. This allows me to enjoy collaborations with scientists across the world.

I am proud of my development of novel theoretical methods in studying random noise in the dynamics of small, interacting particles and complex systems like neurons. Noise is any disturbance that interferes with data transmission or communication. Such research is important now because devices are becoming smaller and smaller, and noises are affecting their performance. This research has helped me a lot in the analysis of memristive devices, where nanoparticle diffusion is very noisy, and random noise plays a key role in the performance of memristors.



ARE WE GIVING YOUNG PEOPLE THE CAPABILITIES THEY NEED TO SUCCEED?

IN THE 1980S, NOBEL PRIZE-WINNING ECONOMIST AMARTYA SEN CHALLENGED TRADITIONAL WELFARE ECONOMICS WITH HIS CAPABILITIES APPROACH – A CONCEPT THAT FOCUSES ON A PERSON’S ACTUAL CAPABILITY TO ACHIEVE WELL-BEING OR LIFE SUCCESS, RATHER THAN IT BEING A MERE RIGHT. CAN THIS APPROACH BE TRANSLATED INTO OUR EDUCATION SYSTEM? **SHAUN MCINERNEY**, EDUCATION CONSULTANT AND SENIOR PROJECT COORDINATOR FOR **ASHOKA** AND THE **EDGE FOUNDATION** IN THE UK, EXPLAINS HOW THEIR ‘NEW CAPABILITIES FOR A NEW WORLD’ PROGRAMME AIMS TO HELP SCHOOLS IN GREATER MANCHESTER PREPARE YOUNG PEOPLE FOR AN UNCERTAIN FUTURE

WHAT DOES NEW CAPABILITIES FOR A NEW WORLD AIM TO DO?

New Capabilities for a New World is a year-long leadership and strategic development programme for headteachers focused on deeper approaches to personal development, careers and the life-readiness of young people. The programme asks: How do we, as school leaders, develop new capabilities that help us set our young people up for success in a complex and changing world? This is a meaningful response to the articulated desire of young people in Greater Manchester for a more relevant curriculum, and also to the inequalities and levelling-up agenda. The programme supports headteachers to think through how they can best respond at this historical moment of rising youth unemployment, rapid technological change and the climate crisis.

Too often, students are asking, “Why am I learning this? Why is this relevant?”. This has real implications for schools, engagement and, ultimately, achievement. Schools are trying to answer those questions,

but they don’t find it easy because of high-stakes accountability. Inevitably, schools are focused on attainment as a measure of success. New Capabilities is a welcome opportunity to think about a wider purpose of education and the deeper leadership that makes that possible – not at the expense of attainment, but alongside it.

Equity and social disadvantage are another agenda for this programme. In England, we spend £2.5 billion per year on pupil premium (funding to improve education outcomes for disadvantaged pupils in schools) and evidence shows that the impact of this funding is marginal. My sense, and the sense of quite a lot of people, I think, is that we’re leaning the ladder against the wrong wall. It’s hard to serve disadvantaged students well solely by encouraging them to attain more qualifications. This might be part of the story but it’s not the answer to success in life. In the programme, we explore emerging evidence around this that points to the importance of the relationships young people need and the networks that enable their success.



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WHY IS THE PROGRAMME CENTRED AROUND GREATER MANCHESTER?

International NGO, Ashoka, centred its Everyone a Changemaker work initially in Greater Manchester because it's a naturally forward-thinking city region. Greater Manchester has a tagline: 'We do things differently around here'. Greater Manchester's economic strategy for inclusive, zero-carbon growth relies on a culture of innovation and a forward-thinking approach to skills – and this is embodied by the Skills Team at Greater Manchester Combined Authority (GMCA), who are a partner on the New Capabilities programme. In addition, the Edge Foundation has a national reach and has been central to this collaborative impact project and the New Capabilities programme. The University of Manchester has also been a valuable partner.

HOW WERE THE 20 HEADTEACHERS ON THE PROGRAMME SELECTED?

They agreed to work with us voluntarily. We did a few information and taster sessions around the idea of changemaking, being a changemaker and what that means for education. Back in 2015, Matthew Moss High School in Rochdale was one of 15 schools selected by Ashoka as a changemaker school because of their innovative work. So, we've anchored the project there, and have explored the changemaker culture they have created and how that is creating agency and empathy in staff and students.

HOW MUCH AUTONOMY DO SECONDARY HEADTEACHERS HAVE?

More than they feel empowered to use, I'd say. Having led a school, I understand the constraints. OFSTED doesn't want schools to backtrack GCSE exam provision to Key Stage 3, it wants Key Stage 3 to be about deep learning and preparing learners for Key Stage 4. But you can understand the pressures that teachers and schools feel they're under, especially with such a knowledge-intensive GCSE programme.

CAN YOU GIVE AN EXAMPLE OF CHANGEMAKING THROUGH THE NEW CAPABILITIES PROGRAMME?

One example is an eco-literacy project at Little Lever School in Bolton. An Ashoka Fellow who leads The Impact Trust, which focuses on sustainability education, is working with the school's Associate Assistant Principal. They're doing a piece of work for Key Stage 3 geography, which involves putting young people – their perspectives on the environment, how the system needs to change and what their role is in this – at the centre. They've invited industry professionals and conducted a teach-back about certain elements of the curriculum to upscale industry professionals about the climate emergency, green skills, biodiversity and so on.



WHAT PHASE IS THE NEW CAPABILITIES PROGRAMME IN?

There are three phases to the programme. We have introduced new concepts such as changemaking, social capital and developmental relationships. The second phase is putting these concepts into practice and the third phase is around systems leadership. The group has identified quite high-level projects, or changes they want to see in their schools, and they're now in the process of grounding them in strategy and practice.

One big emerging theme is co-leadership – introducing a methodology where young people and school leaders sit down together and think about changemaking collaboratively.

WHAT EXCITES YOU ABOUT THIS PROGRAMME?

Two things. The first is allowing headteachers to feel that their well-being, development, deeper learning and sense of purpose is growing beyond the national professional qualifications (NPQ) framework.

The second is exploring new ways of tackling inequity. If the practice that emerges from this programme helps us shine a light on things that

might work for certain cohorts of disadvantaged young people, that's got to be a step in the right direction.

WILL THE NEW CAPABILITIES PROGRAMME BE REPLICATED IN OTHER REGIONS OF THE UK?

This is a pilot programme, a proof of concept. The initial feedback is really strong and there are some green shoots of impact. We're rigorously evaluating the programme with the Careers and Enterprise Company to understand what is working, and how, so that the learning can be of use to others. Hopefully, as well as deepening this work in Greater Manchester, we'll work with another cluster region next year.

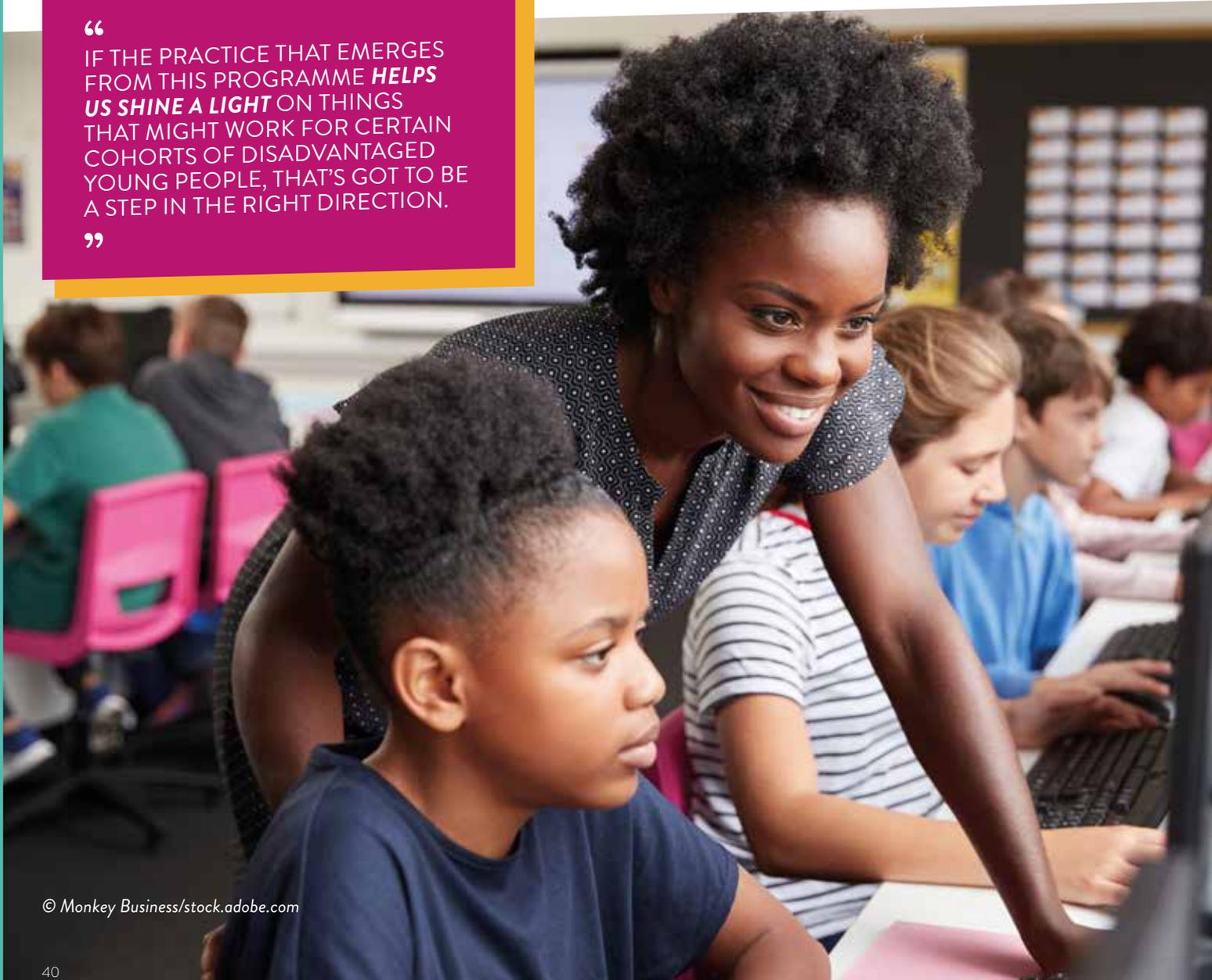
WHAT MESSAGE WOULD YOU LIKE TO SEND TO HEADTEACHERS AND TEACHERS READING THIS ARTICLE?

By stepping back, pausing and engaging in a process of deeper learning and collaboration, we're able to surface new ways of doing things. Drawing on the expertise of Ashoka around changemaking, and best practice in real world learning from Edge, can help us connect with our wider purpose, and unlock the potential and long term success of young people.

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IF THE PRACTICE THAT EMERGES FROM THIS PROGRAMME **HELPS US SHINE A LIGHT** ON THINGS THAT MIGHT WORK FOR CERTAIN COHORTS OF DISADVANTAGED YOUNG PEOPLE, THAT'S GOT TO BE A STEP IN THE RIGHT DIRECTION.

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WHY IS THE PROGRAMME CALLED ‘NEW CAPABILITIES FOR A NEW WORLD’?

The 1998 Nobel Prize-winning economist, Amartya Sen, challenged the world of development economics by introducing the notion of capability. In traditional development thinking, Gross Domestic Product is considered the main vehicle for progress and economic development, and therefore human welfare. Amartya’s capabilities approach, however, argues that well-being is of primary moral importance and should be understood in terms of people’s capabilities and functionings – not just the resources they have, but how those resources enable them to live.

The *Stanford Encyclopaedia of Philosophy* describes Amartya’s capabilities as “the doings and beings that people can achieve if they so choose”, in other words, their opportunity to do or be certain things (for example, well-nourished, married, educated, well-travelled). Functionings are capabilities that have been realised.

“Human freedoms and development are expanded, or not, based on the number of capabilities they have,” says Shaun. “And those capabilities

are dependent on a set of functionings that either enable that freedom to happen or not. If we examine the education system, we have a set of qualifications that don’t guarantee functioning in the world. Introducing the idea of long-term capabilities will hopefully help us take responsibility for how the education system equips young people to function in the world using the capabilities they have, rather than just being concerned with what they leave with when they exit the school gates.

WHO’S INVOLVED?

New Capabilities for a New World is a partnership between Ashoka UK, the Greater Manchester Combined Authority Careers Hub, Edge Foundation, and the Careers and Enterprise Company.

ABOUT SHAUN



Shaun is the programme lead and architect of New Capabilities for a New World. He works with Ashoka and the Edge Foundation and is an Honorary Research Fellow at the Alliance MBS Business School, at the University of Manchester. Shaun has spent much of his career tackling inequality as a school leader and Executive Principal in inner city Liverpool.

“The template for this is my own experience with working class young people and recognising that it is through broadening their horizons, putting them into real-life situations, making their learning relevant and building their confidence by supporting them to function in new situations, with new people. This is what allows them to get ahead.”

PROSTHESES FOR PEOPLE: MATCHING THE PERSON AND THEIR NEW LIMB

WORLDWIDE, THE MAJORITY OF AMPUTEES DO NOT HAVE ACCESS TO A USEFUL PROSTHESIS. THIS IS ESPECIALLY TRUE IN LOWER & MIDDLE INCOME COUNTRIES (LMICS) WHERE LIMB LOSS MAY BE MORE COMMON AND SERVICES LESS ACCESSIBLE. MECHANICAL ENGINEERS PROFESSOR LAURENCE KENNEY AND DR ALEX DICKINSON ARE WORKING WITH PEOPLE IN DIFFERENT PARTS OF THE WORLD TO MAKE PROSTHESES AS ACCESSIBLE AND USEFUL AS POSSIBLE

TALK LIKE A MECHANICAL ENGINEER

MECHANICAL ENGINEERING – the branch of engineering that focuses on the design, construction and use of machines

ORTHOPAEDIC – the branch of medicine that addresses deformities or losses of bones and muscles

PROSTHETICS – the branch of science/medicine involving the design, construction and fitting of artificial body parts

PROSTHESIS – an artificial body part

UPPER LIMB – includes the shoulder, arm (the upper arm), elbow, forearm (the lower arm) and the hand

PROSTHETIST-ORTHOTISTS – a medical practitioner specialising in prosthetics and orthopaedics

NEWTON (N) – the unit of force

Human limbs are complex, so building mechanical replacements is no easy task. Despite major steps forwards in the science of prosthetics, there are still barriers to overcome in terms of making prostheses accessible, useful and specific to their user.

When Professor Laurence Kenney and Dr Alex Dickinson began their projects, they recognised that engineering alone cannot provide all the answers and that interdisciplinary collaboration would be essential to build devices that work for real people in the real world.

PROSTHETICS: FROM SCIENCE TO APPLICATION

Limb losses can occur from a multitude of injuries, diseases or genetic abnormalities. The science behind prosthetics is always becoming more sophisticated, with the most advanced prostheses having almost the same range of movements and functions as the limb they replace. However, such sophisticated models are staggeringly expensive and, for most prosthesis wearers and the healthcare systems that support them, more affordable solutions are needed. Alex explains, “Another issue is that the more precisely a prosthesis matches the function of the real limb, the less durable it is likely to be.”

Every person in need of a prosthesis will have a different set of circumstances, a different body on which the prosthesis needs to fit and differing requirements for what they need the prosthesis to fulfil. For instance, while some people may want a prosthesis purely for aesthetic purposes, others may need a functional prosthesis to sustain their livelihood. Overall, this means that it is impossible to mass-produce prostheses if they

are to be effective; a bespoke approach is needed to tailor each prosthesis to the person it will fit.

A FOCUS ON LOWER MIDDLE INCOME COUNTRIES

Although the precise figure is not known, it is estimated that around 57.7 million people globally have suffered from a limb amputation stemming from a traumatic incident. Around 38% of these suffer from upper limb loss. “It’s also estimated that 64% of amputees live in LMICs, and their average age tends to be younger than in higher income countries,” explains Laurence.

There are several reasons why the majority of amputees may be concentrated in LMICs. Many of these nations have experienced conflict in recent decades, and even if the war may have ended, its legacy can live on in the form of unexploded landmines. When a landmine is stepped on, the ensuing explosion can easily lead to the victim losing a limb. “Other common causes of upper limb loss in LMICs include road traffic accidents and poor access to medical services, which could prevent a relatively minor affliction from progressing to a stage where amputation is needed,” says Laurence.

THE CASE OF CAMBODIA

Cambodia, where Alex’s project is focused, is a prime example of a nation with a higher-than-average need for prostheses. Brutal



EXPLORE CAREERS IN MECHANICAL ENGINEERING

- Alex recommends getting as much experience as possible, such as through work experience or volunteering. Contacting a range of relevant organisations close to you can open doors – Alex recalls spending his school and university holidays working in a Formula 3 team, helping a team restore a crashed Hurricane WW2 fighter, and investigating failed helicopter parts.
 - The Institute of Mechanical Engineers runs activities for schools, supports teachers, and provides useful careers advice: www.imeche.org/careers-education
- The Royal Academy of Engineers has a comparable range of resources with a broader engineering focus: www.raeng.org.uk/education
- Talking to your school about bringing engineering into the classroom can provide inspiring experiences and potentially useful contacts or entry points into the field. The Primary Engineer Programme (www.primaryengineer.com) and Stem Ambassador Programme (www.stem.org.uk/stem-ambassadors/schools-and-colleges) both provide courses for students of all ages.
- According to Prospects UK, starting salaries for mechanical engineers on graduate training programmes range from £20,000 to £28,000: www.prospects.ac.uk/job-profiles/mechanical-engineer

conflicts in the 1970s and 1980s, such as during the Khmer Rouge regime, included the placing of as many as ten million landmines. This has led to the nation having one of the highest amputation rates in the world. “Cambodian authorities and charities that work in the country have a lot to be proud of in terms of clearing landmines, providing prosthetic limbs and supporting prosthetic limb users with other services,” says Alex.

Despite these successes, a lot of work remains. “You may think that the barrier to helping these people is the cost of prosthetic limbs, but we already have some very robust, long-lasting and relatively inexpensive prostheses,” says Alex. “Bigger barriers to providing prosthetic limbs to people in LMICs are the lack of trained professionals and access issues, as many people live far away from clinics and are unable to travel or take time away from work.”

UGANDA AND JORDAN

“Globally, the World Health Organization

estimates that only between 5 and 15% of people who need a prosthesis have access to one,” says Laurence. In Uganda, one of the least developed countries in the world, his team found that the absence of government support meant that the orthopaedic workshops in government-run hospitals were typically under-supplied with the equipment and materials they needed. “The lack of a coordinated purchasing system means that prices are high and patients often have to buy the materials they need themselves,” says Laurence. “For instance, we found that the cost of polypropylene, a plastic commonly used in prosthetics and many other applications, was about five times higher in Uganda compared to the UK.”

Jordan suffers less from poverty than Uganda and has a developed clinical infrastructure with well-trained staff. However, regional conflicts are catalysing the loss of limbs and destabilising the economy. “While service provision in Jordan is better than in Uganda, cost remains a barrier to many,” says Laurence. The different needs of people

within these two countries are supplying useful lessons for the team, making it clear that there is no ‘one size fits all’ solution to making prostheses accessible to those who need them.

PATHWAY FROM SCHOOL TO MECHANICAL ENGINEERING

Both Alex and Laurence say that A-levels (or equivalents) in maths and physics are typically required for undergraduate degrees in mechanical engineering. Alex recommends thinking outside the box for different additional subjects, citing the importance of a broad skillset. Options include chemistry, languages, electronics, computing, design, music and art.

PROFESSOR LAURENCE KENNEY: FIT-FOR-PURPOSE-AFFORDABLE BODY-POWERED PROSTHESES

Laurence's project involves teams working in Uganda and Jordan to understand the differing regional and individual challenges facing effective use of prostheses in those nations. With this information, they are improving body-powered prostheses.

Body-powered prostheses are upper limb replacements that incorporate mechanical components that can be moved by the wearer, allowing them to grasp objects. "Traditional body-powered prostheses consist of a mechanically operated 'hand', often a 'split hook', attached via a cable to a shoulder harness," explains Laurence. "Movement of the shoulder pulls on the cable which in turn either pulls the 'hand' open or closed, depending on the configuration." Designs are relatively low-cost and typically cope well with wear and tear.

However, body-powered prostheses also tend to be unpopular. Designs have changed little over the last 100-odd years and users report limited functionality and some discomfort, leading to high rates of rejection. One fundamental issue lies in the inefficiencies of the underlying mechanics, which is where Laurence's expertise can help. "In a worst-case scenario, a force of over 130 N was needed to get the prosthesis to grip an object with a force of 15 N!"* says Laurence. "This means that operating the prosthesis can quickly become tiring." The team found that the range of movement when using such body-powered prostheses was limited, including both where the 'hand' could be positioned relative to the rest of the body, as well as the ability to fully open or close the 'hand'.

LIVED EXPERIENCES

Though these functional benefits and limitations can be explored in a workshop, understanding how they are used in the real

world involves interacting with prosthesis users. Laurence's team includes a social scientist and a health psychologist, who specialise in collecting such information. These two individuals trained teams of interviewers within Jordan and Uganda. "Once trained, the interviewers invited people with upper limb absence to talk about their experiences and expectations of prostheses," says Laurence. "The researchers then used a technique called 'thematic analysis' to pull out the key features and themes from the recordings."

Their findings were fed back to the mechanical engineers. Though they originally planned to concentrate on increasing the efficiency of prostheses, the findings from the interviews suggested that development of a simpler overall design may be of more benefit to prosthesis users. "We have decided to design a hand which doesn't rely on shoulder harness-control for its operation," explains Laurence. "The hand design problem is a compromise between the appearance of the hand and its function. We learnt that the ability to perform tasks such as farming and household chores are important to the population we were designing for." Comfort was also highlighted, so the team has expanded its work to include designing a socket that can be made easily, fitted comfortably and potentially repaired locally.

PARTNERS

As well as working across different scientific disciplines, there is a lot of value in working with partners from outside academia. In Jordan, the team has been advised by the International Committee of the Red Cross (ICRC) and Médecins Sans Frontières (MSF), two well-known and respected international charities that have plenty of experience working with LMICs, both understanding limitations and opportunities, as well as having

useful networks with which the team can connect. "These organisations have been very helpful in keeping our team grounded in the reality of delivering prosthetics services in LMICs," says Laurence.

The Uganda team has also recognised this value. "One of our team, Professor Louise Ackers, also heads up the Knowledge4Change charity, and its involvement in supporting placements in Uganda has been very helpful," says Laurence. "For instance, early in the project, a number of Salford University students and a couple of NHS trainee clinical scientists carried out small projects in Uganda, which greatly helped us to focus our design efforts."

IMPACTS AND HIGHLIGHTS

"I think our impact to date has been in somewhat unexpected areas for an engineering project," says Laurence. "For example, identifying and highlighting the specific issues with the Ugandan prosthetics services has framed the problem, possibly for the first time, and we are trying out ways to address these issues." By expanding its focus to look at the issue from the perspective of individuals' lived experiences, the team has uncovered wider challenges beyond the mechanical design issues that they initially identified.

Laurence believes this engagement with real society has brought its personal rewards too. "The project has, without doubt, been a career highlight for me," says Laurence. "I have thoroughly enjoyed working with enthusiastic and brilliant engineers, social scientists, clinicians and psychologists, as well as learning an enormous amount about the challenges of designing fit-for-purpose prostheses." The project is not finished yet and the teams remain enthusiastic to find ways to further their work beyond the scope of the project.

*Smit G, Plettenburg DH. Efficiency of Voluntary Closing Hand and Hook Prostheses. *Prosthetics and Orthotics International*. 2010;34(4):411-427. doi:10.3109/03093646.2010.486390



**PROFESSOR
LAURENCE KENNEY**

School of Health and Society, University of Salford, Manchester, UK



FIELD OF RESEARCH

Rehabilitation Technologies (Mechanical Engineering)



RESEARCH PROJECT

Assessing the body-powered prosthesis requirements of amputees in Uganda and Jordan to develop optimised prostheses and support improved provision and uptake



FUNDERS

Engineering and Physical Sciences Research Council (EPSRC), National Institute for Health Research (NIHR) Global Challenges Research Fund

HOW DID LAURENCE BECOME A MECHANICAL ENGINEER?

WHO OR WHAT INSPIRED YOU TO BECOME AN ENGINEER?

My dad was a chemical engineer, and I can remember taking down his master's thesis from the shelf in the front room and being intrigued by the maths, which at that age seemed like a really exciting puzzle to decode. I also very much enjoyed maths at school.

WHAT LED YOU TO SPECIALISE IN REHABILITATIVE TECHNOLOGIES?

As a child, I had Perthes Disease, which is a softening of the top of the thigh bone due to a restricted blood supply. For periods, I was in hospital and, later, underwent a quite complex operation. For some of the time during these periods, I was a wheelchair user. The operation and rehabilitation were both very successful and I went on to take up rock climbing and hill walking as an adult. The potential positive impacts of rehabilitation engineering were, therefore, very clear to me!

WHAT ARE YOUR PROUDEST CAREER ACHIEVEMENTS, SO FAR?

For a couple of years in the late 1990s, I worked in the Netherlands as part of a

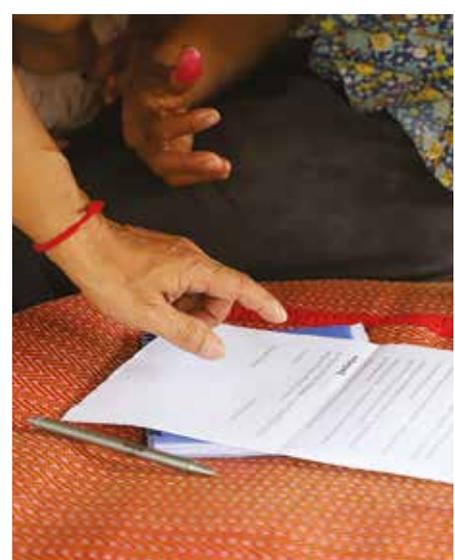
team developing an implantable electrical stimulator which could be used by people with impaired walking. We worked with a UK-based company, Finetech Medical, who later made the device available for regular clinical use. I think my proudest moment was witnessing the first operation to implant the system.

WHAT CHALLENGES WILL BE ADDRESSED BY MECHANICAL ENGINEERS OF THE FUTURE?

The two obvious challenges are green technologies to address the climate emergency, and the delivery of more efficient and better healthcare. Personally, it is pleasing to see many more engineers now choosing to focus on these areas rather than, for example, developing 'better' weapons.

LAURENCE'S TOP TIP

If it interests you, choose mechanical engineering! It opens up enormous possibilities for a varied and rewarding career.



A participant giving consent to the researchers by signing the form with her thumb-print using a community worker's lipstick. This reflects the value of user-centred research and the low literacy levels in some of the places where the research took place.
© Laurence Kenney

DR ALEX DICKINSON: A STEP CHANGE IN LMIC PROSTHETICS PROVISION THROUGH COMPUTER AIDED DESIGN, ACTIMETRY AND DATABASE TECHNOLOGIES

Alex's project involves working in Cambodia to find data-technology solutions to help people access prostheses that work for them. Developing these solutions also involves developing a deep understanding of the context of the issue.

TECHNOLOGY TO TAILOR PROSTHESES

Alex's team identified that, in Cambodia, it was not the functionality of prostheses but rather access to surrounding services that was limiting uptake and use of prostheses. "Instead of developing new prosthetic limbs, we wanted to see whether we could support improving access to prosthetics services by developing and introducing digital tools," he explains.

For instance, given that every person who needs a prosthesis will have different body characteristics and residual limb (sometimes called 'stump'), there is a need to account for these individual differences to ensure their prosthesis is comfortable and useful. "What makes matters worse, over time the residual limb changes shape considerably! 3D scanning can measure the shape of a residual limb, and we wanted to enable this procedure to be performed by a travelling prosthetist to assess when a new prosthesis is needed, so that people don't need to make long journeys or take time off work," says Alex.

The team is also investigating fitting digital sensors on prostheses, which record how patients use the limbs in their daily lives, helping prostheses be better tailored to their needs. "By bringing together the data from these different digital tools, we can understand more about the value offered by prosthetic limbs and services, which will help charities and the government to justify why they need ongoing funding, and to make best use of it," says Alex. Given that prostheses need to be replaced every few years, this recorded data

will also help the creation of a person's next prosthesis more closely fit their needs.

BUILDING ROBUSTNESS

Because Alex's team needs its sensors and scanners to be used by researchers and prosthesis users in the wider world, rather than solely by clinicians in hospitals or labs, there are a number of other factors to bear in mind. "It is important that our sensors and scanners are durable so that they work well in hot temperatures and dusty, humid environments, so part of our work is testing and selecting from the best sensors and scanners already available," explains Alex.

The team also wants to ensure its devices are reliable, giving accurate and meaningful measurements. "For instance, it's important that 3D scans give the same information if the same leg is scanned several times, or by different people," says Alex. "On top of that, we need to collect, store and synchronise a person's clinical data records safely, and ensure we have their informed consent, so a big part of our project was creating a system which would manage their data in a secure and ethical way."

PARTNERING UP

"It is essential for our research to include a team with a wide range of experiences, because it is impossible for any one specialism to have all the skills needed to do this kind of work," says Alex. While biomechanical engineers understand how the body works and how it can be measured, computer scientists and software engineers can ensure that data is managed effectively and kept secure.

In addition, it is important to ensure that these measurements and recordings actually have useful applications for their end users. "Our approach involves working carefully with a healthcare psychologist, clinicians, a

business modeller and prosthetic limb users themselves to understand what we actually need to measure – measuring something that matters to the person and their community," explains Alex.

Outside of science, Alex's team partnered up with the charity Exceed Worldwide, which helped their work reach the people that needed it most. "Exceed Worldwide provides prostheses and runs a school which trains people to become certified prosthetist-orthotists who design and fit people with prosthetic limbs, and technicians who make and repair them," he says. Being able to access this network ensured that the team's creations would have practical value.

SUCCESSES AND NEXT STEPS

The team has made a lot of progress in developing and deploying digital tools and has confidence that its tools work in the real world. This will help inform the further development of similar tools, acting as a 'benchmark' to compare future efforts to. "Another big success in my opinion is that we did this work with four Cambodian student prosthetist-orthotists, as part of their final-year projects," says Alex. "They are now more confident to do research and were able to present their work at an international prosthetics and orthotics conference."

Next, the team hopes to expand its work further afield. "By analysing similar data in many more places, we can help clinics and other service providers to make more confident decisions about which are the most effective prosthetic limbs for their patients and let them build the evidence to ensure they can keep getting funding to do their highly important work of providing people with prosthetic limbs," says Alex.



DR ALEX DICKINSON

Associate Professor in Mechanical Engineering, University of Southampton, UK

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FIELD OF RESEARCH

Mechanical Engineering

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RESEARCH PROJECT

Developing digital measurement tools and a network of data for prosthetic fittings and use, alongside ethnographic research to ensure developed technologies are practical

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FUNDERS

Engineering and Physical Sciences Research Council (EPSRC), Royal Academy of Engineering (RAEng), Innovate UK

HOW DID ALEX BECOME A MECHANICAL ENGINEER?

WHO OR WHAT INSPIRED YOU TO BECOME AN ENGINEER?

Both my grandfathers were engineers (one by profession, and the other at home in the garage) so I became an engineer due to nature and nurture!

WHAT LED YOU TO SPECIALISE IN BIOMECHANICS?

I discovered biomechanical engineering by accident. I started studying mechanical engineering so that I could work in motorsport or the aerospace industry. For my dissertation, I was allocated my last choice of project, covering a carbon fibre hip replacement. I was disappointed for about two hours, until I started reading about the topic. I found out that some patients were still being fitted with implants similar to those developed in the 1960s and I realised there was a need to tackle some really fundamental challenges in biomechanics.

WHAT ARE YOUR PROUDEST CAREER ACHIEVEMENTS, SO FAR?

I am proud of seeing the hip replacement implants I helped develop in my first

graduate job enter into clinical use and being implanted by surgeons around the world. More recently, I have been very proud to see my students defend PhDs, become doctors and go on to exciting jobs, including starting a company developing software to design prosthetic limbs.

WHAT CHALLENGES WILL BE ADDRESSED BY MECHANICAL ENGINEERS OF THE FUTURE?

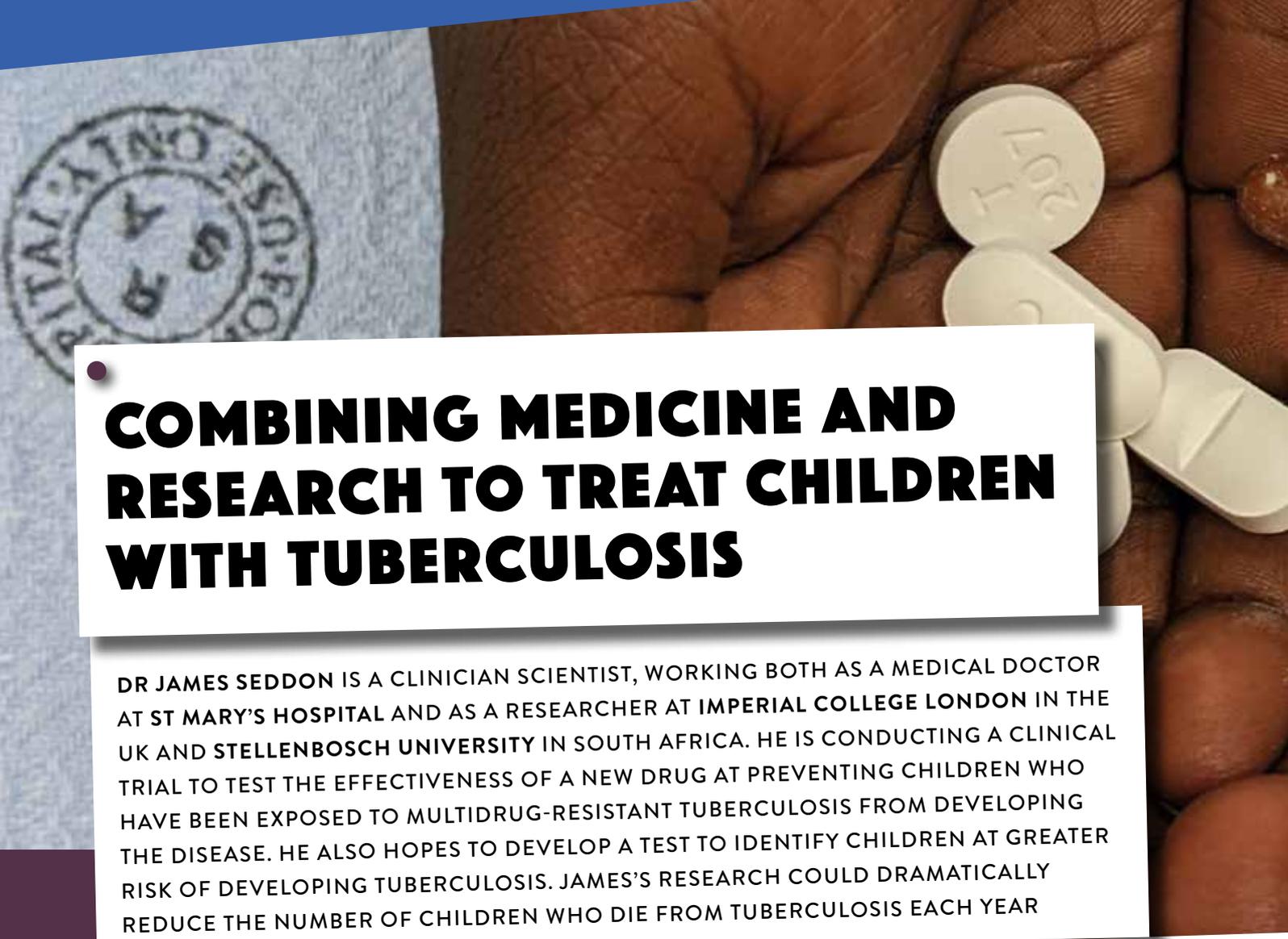
I think we have a real challenge of balancing development, to make our lives easier and better, against sustainability, as we become more aware of our limited resources and our impact on the environment. I'm very encouraged by the awareness of these issues we now see in schoolchildren and students.



In Cambodia, travelling community workers play an essential role in supporting people accessing prosthetics and orthopaedic services.

ALEX'S TOP TIP

Do something you enjoy! If you like making things, writing code, building kits or fixing things, or even just taking things apart to see how they work, you might already be thinking the way an engineer does. More than that, just look at the objects in the world around you and ask yourself lots of 'why?' questions: Why is it that shape? Why is it made from that material? Why don't we do that in a different way?



COMBINING MEDICINE AND RESEARCH TO TREAT CHILDREN WITH TUBERCULOSIS

DR JAMES SEDDON IS A CLINICIAN SCIENTIST, WORKING BOTH AS A MEDICAL DOCTOR AT ST MARY'S HOSPITAL AND AS A RESEARCHER AT IMPERIAL COLLEGE LONDON IN THE UK AND STELLENBOSCH UNIVERSITY IN SOUTH AFRICA. HE IS CONDUCTING A CLINICAL TRIAL TO TEST THE EFFECTIVENESS OF A NEW DRUG AT PREVENTING CHILDREN WHO HAVE BEEN EXPOSED TO MULTIDRUG-RESISTANT TUBERCULOSIS FROM DEVELOPING THE DISEASE. HE ALSO HOPES TO DEVELOP A TEST TO IDENTIFY CHILDREN AT GREATER RISK OF DEVELOPING TUBERCULOSIS. JAMES'S RESEARCH COULD DRAMATICALLY REDUCE THE NUMBER OF CHILDREN WHO DIE FROM TUBERCULOSIS EACH YEAR

TALK LIKE A CLINICIAN SCIENTIST

BACTERIA – single-celled microorganisms, some of which affect humans in beneficial or harmful ways

TUBERCULOSIS (TB) – a potentially-fatal bacterial infection that mainly affects the lungs and usually causes coughing, fever and weight loss

MULTIDRUG-RESISTANT TUBERCULOSIS (MDR-TB) – a form of TB where the bacteria is resistant to the best anti-TB drugs

PAEDIATRICIAN – a medical doctor who diagnoses and treats health conditions in children

CLINICAL TRIAL – a type of scientific study used to test the effectiveness of a medical treatment

PLACEBO – a non-active treatment given to participants in clinical trials

In 2020, 1.1 million children worldwide were estimated to develop tuberculosis (TB), a potentially fatal disease that primarily affects the lungs and usually causes coughing, fever and weight loss. TB is caused by the bacteria *Mycobacterium tuberculosis*, and when someone with TB coughs, these bacteria are released into the air. If someone else breathes them in, these bacteria enter that person's lungs, resulting in TB infection. Many people with TB infection never become unwell, as their immune system controls the bacteria in the body, but sometimes the number of bacteria increases, at which point the person develops TB disease and becomes unwell.

The good news is that doctors can test for TB infection before the onset of TB disease, enabling patients to be treated with drugs to ensure they do not progress to disease. However, some forms of TB bacteria have evolved to become resistant to the standard anti-TB drugs, resulting in multidrug-resistant (MDR) TB. If someone is infected with MDR-TB, normal treatments are ineffective, and doctors cannot prevent them developing the disease.

Dr James Seddon is a clinician scientist working as both a paediatrician and researcher, who divides his time between St Mary's

Hospital and Imperial College London in the UK, and Stellenbosch University in South Africa. James is conducting research into childhood TB in South Africa, to establish whether a new drug can prevent children who have been exposed to MDR-TB from developing TB disease. He also hopes to develop a gene expression test to identify children at higher risk of developing the disease, so treatments can be targeted more efficiently.

WHAT HAPPENS DURING A CLINICAL TRIAL?

James and his colleagues are running a clinical trial to test whether a new drug, levofloxacin, is safe and effective at preventing TB disease in children who have been exposed to MDR-TB. Normally, when someone is diagnosed with TB, the children in their household are given anti-TB drugs to prevent future TB. But if the person with TB is diagnosed with MDR-TB, then the normal drugs that are given to prevent future TB are ineffective and so no treatment can be given to children in the household.

James's team contacts adults who have been diagnosed with MDR-TB. If they live with any children under the age of five, they are asked whether they would like the child to join the



clinical trial. To determine whether levofloxacin prevents children exposed to MDR-TB infection developing TB disease, James must assess how many children progress to the disease when taking the drug, compared to how many progress to the disease without treatment.

Each child is randomly assigned to either receive levofloxacin tablets or a placebo (a dummy pill that doesn't contain any treatment). "Neither the research team nor the families know which children are receiving levofloxacin treatment and which are receiving the placebo," explains James. "This is important, because if people knew which medicine the child was receiving, it may influence how they are treated which in turn may affect the study results." This is called a 'double-blind' clinical trial.

The children take the tablets for six months, during which time they are examined by the medical team every few weeks. The medical team continues to regularly assess every child for a year after they finish their treatment. Any children who develop TB disease will be diagnosed early and will receive the best possible treatment. "We hope that even the children receiving the placebo will be better off than children exposed to MDR-TB who are not in the trial," says James.

WHAT RESULTS DOES JAMES EXPECT TO SEE?

"We expect fewer of the children who are

given levofloxacin to progress to TB disease, compared to the children given the placebo," says James. If this is the case, and assuming there are no adverse side effects of the drug, then this will be good evidence that levofloxacin is safe and effective at preventing TB disease in children exposed to MDR-TB. It will then be the responsibility of health policy makers to introduce this new drug to global health policies. "We would hope that if we find that levofloxacin reduces risk of TB disease progression and is safe, then the World Health Organization will recommend that, in future, all children who have been exposed to MDR-TB should be given levofloxacin," James says.

HOW CAN A CHILD'S TB RISK BE DETERMINED?

Throughout the course of the trial, blood samples are taken from every child at regular intervals and tested to ensure the drug is safe. James and his colleagues are also analysing these blood samples to determine which genes are activated in each child at each point in time. By comparing the activated genes in children who progress to TB disease with the activated genes in children who remain well, James hopes to identify which activated genes can tell these two groups of children apart. A clinical test could then be developed so that when a child is exposed to TB, their risk of developing TB disease can be determined by testing for these few key activated genes.



DR JAMES SEDDON

Consultant, Department of Paediatric Infectious Diseases, St Mary's Hospital, London, UK

Reader in Global Child Health, Department of Infectious Diseases, Imperial College London, UK

Associate Professor, Desmond Tutu TB Centre, Stellenbosch University, South Africa

FIELD OF RESEARCH

Childhood Tuberculosis

RESEARCH PROJECT

Conducting a clinical trial to determine the effectiveness of levofloxacin at preventing TB disease in children and developing a gene expression test to identify children at risk of developing TB

FUNDER

Medical Research Council (MRC)

This gene expression test would involve taking a small blood sample from the child by pricking their finger and analysing this blood in a machine that identifies the key activated genes within about half an hour. Children most at risk of developing TB disease could then be given appropriate treatment. This would enable countries with high rates of TB to prioritise their often-limited medical resources for children who most need them.

"If this kind of test were widely available, it could dramatically increase the number of children who are appropriately given treatment for TB infection and reduce the number of children who develop TB and who die from the disease each year," says James.

ABOUT CLINICIAN SCIENTISTS

A clinician scientist works as both a medical doctor treating patients and as a researcher in their specialist field. James is a paediatrician who looks after children with infectious diseases while also conducting research to find new tests and treatments for those diseases. He feels these roles complement each other well.

“The clinical work keeps me on my toes, making me aware of the most important questions that need answering to improve the care of children,” he says. “The research is very satisfying as it allows me to answer some of those questions, by changing the way we understand, diagnose and treat diseases.” But this dual role can also be challenging. “By doing two separate jobs, you feel that you are never giving either of them enough of your attention.”

WHAT DOES A CLINICIAN SCIENTIST'S DAY LOOK LIKE?

On clinical days, James visits his patients and works with health staff to decide what tests and treatments each child might need. He also advises other paediatricians about infectious diseases. He is often on-call overnight, ready to go into the hospital if he needs to attend to his patients.

On research days, James mainly does analysis and writing at his computer and sometimes sees children clinically who are taking part in his studies. Research projects can take years from start to finish, and they involve multiple stages: developing ideas and project proposals, applying for funding and ethics approval, collecting and analysing data, and finally, getting the research published. James always

has lots of projects on the go, all at different stages. As research is a collaborative effort, this means he attends lots of meetings with his colleagues to discuss the progress of projects.

WHAT PERSONAL QUALITIES SHOULD CLINICIAN SCIENTISTS HAVE?

James says that anyone pursuing a career as a clinician scientist should be open minded and continually asking questions about the world, like ‘how can this be improved?’ or ‘how can we understand this better?’ Being organised and able to multitask are also useful skills. Clinical work and research are both team activities so it is vital that you can work well with other people.

EXPLORE CAREERS AS A CLINICIAN SCIENTIST

• It is important that clinician scientists are interested both in treating patients and in scientific research. The following articles written by clinician scientists highlight the rewards and challenges of the job:

- www.ncbi.nlm.nih.gov/pmc/articles/PMC4485885

- journals.biologists.com/dmm/article/3/3-4/125/2335/Interested-in-a-career-as-a-clinician-scientist

• University outreach programmes can help you learn more about both aspects of this career. Imperial College London offers activities for young people to learn about science (www.imperial.ac.uk/be-inspired/schools-outreach) and medicine (www.imperial.ac.uk/be-inspired/schools-outreach/secondary-schools/stem-programmes/pathways-to-medicine). Stellenbosch University has an extensive social impact programme (www.sun.ac.za/si/en-za/Pages/default.aspx), including an initiative to introduce high school students from disadvantaged communities to the Faculty of Medicine and Health Sciences (www.sun.ac.za/si/en-za/Pages/initiative.aspx?iid=1046)

PATHWAY FROM SCHOOL TO CLINICIAN SCIENTIST

- At school, science subjects such as biology and chemistry are necessary for studying medicine at university.
- James also studied English and history, which taught him to think critically, question ideas and communicate clearly, all of which are crucial skills for researchers. “I would suggest doing subjects that you are passionate about, that you are good at and that teach you to develop critical thinking,” he advises.
- As a medical doctor and a researcher, you must train and qualify in both these areas which will take several years. A degree in medicine takes five or six years in the UK (www.healthcareers.nhs.uk/explore-roles/doctors/training-doctor) and six years in South Africa (www.sun.ac.za/english/faculty/healthsciences/Pages/MBChB.aspx), both followed by many years of further clinical training to become a specialist. To become a research scientist (nationalcareers.service.gov.uk/job-profiles/research-scientist), you will usually need to complete a PhD, which typically takes three to four years.
- James highlights that you don't have to be a doctor to do research into health-related topics. Your clinical training could be in another field, such as nursing, pharmacy or psychology, which you could practise alongside your research. Or you could conduct medical research without being a clinical practitioner. In this case, degrees in biomedical science, biochemistry or molecular biology would be useful choices.

JAMES'S TOP TIPS

- 01 I think that the most important thing is to keep doing things that you find interesting and rewarding. Have confidence that they will take you somewhere worthwhile.
- 02 Always make sure you work with people you like, trust and respect. Life is too short to do otherwise!



HOW DID JAMES BECOME A CLINICIAN SCIENTIST?

Medicine and research have been in my blood since I was young – my mother, grandfather and uncle were doctors, and my father and other grandfather were academics. My parents encouraged me think about other careers too, but medicine always felt like the right fit for me, and I continue to love it.

I did a great deal of sport when I was younger. I think participating in group activities (e.g., sport, music or drama) helps young people understand how to work in a team. Teamwork is crucial for both doctors and scientists. When applying for medical school, teamwork is considered an important life skill, so it is good to gain these experiences while at school.

I have a younger brother and sister, so grew up being familiar with how to understand and look after children. At medical school, I really

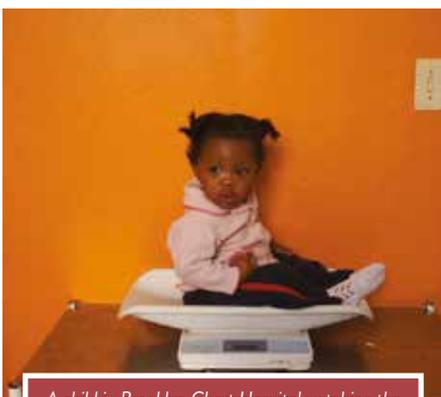
enjoyed my paediatric placement and my decision to be a paediatrician was cemented while working in an emergency department in Australia. Working there, I enjoyed seeing children and their parents because it was usually lots of fun and always felt important.

I realised that childhood TB was an interesting area when I was working with Médecins sans Frontières (MSF) in Côte d'Ivoire. We looked after so many children with TB and HIV. I found it clinically very challenging as we had poor diagnostic tests and very limited drug options. I felt that this was a fascinating area that really needed more research.

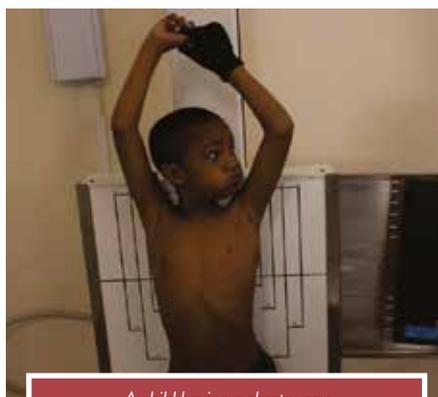
Working for MSF was a real highlight of my career. It was hugely rewarding but also an enormously challenging experience. It was often scary to deliver medical care in unsafe

situations with poor security and, having previously worked in wealthier countries, it was difficult to manage with so few resources. But it was also very satisfying to work with local staff to deliver healthcare where there were few other options. I learnt a great deal, both medically and from a leadership and logistics perspective.

Cape Town and London are two of the most amazing places in the world and I love being able to travel between the two. Most of my research takes place in Cape Town so I spend most of my time there. It is a beautiful place and it is wonderful to be able to do high quality research on a devastating disease like TB, while also being near mountains and beaches. I also love going back to London to work in the hospital, looking after children on the ward with complicated infections.



A child in Brooklyn Chest Hospital watching the world while sitting on the weighing scales.
© Damien Schumann



A child having a chest x-ray to look for evidence of TB.
© Damien Schumann



A child being treated for MDR-TB receiving their daily medication.
© Damien Schumann

HOW CAN WE DISCOVER NEW ANTIBIOTICS?

FIRST DISCOVERED IN THE 1920S, ANTIBIOTICS HAVE REVOLUTIONISED THE WAY WE TREAT INFECTIOUS DISEASE. HOWEVER, THE DISCOVERY OF NEW ANTIBIOTICS HAS BEEN DECLINING SINCE THE MID-1960S AND BACTERIA ARE GRADUALLY DEVELOPING RESISTANCE TO EXISTING ONES, POSING AN URGENT THREAT TO GLOBAL HEALTH. AT PRINCETON UNIVERSITY IN THE US, PROFESSOR MOHAMMAD SEYEDSAYAMDOST HAS DEVELOPED A NEW METHOD TO IDENTIFY NOVEL NATURAL PRODUCTS, POTENTIALLY FAST-TRACKING THE DEVELOPMENT OF NEW ANTIBIOTICS

TALK LIKE A CHEMICAL MICROBIOLOGIST

ANTIBIOTICS – drugs used to treat infections by killing or preventing the growth of bacteria

ANTIBIOTIC RESISTANCE – the process of bacteria acquiring molecular mechanisms that protect from the effects of antibiotics

BACTERIA – single-celled microbes, some of which cause disease

BIOSYNTHESIS – the production of complex molecules within living organisms or cells

BIOSYNTHETIC GENE CLUSTERS – the sets of genes responsible for the production of natural products

CRYPTIC NATURAL PRODUCTS – natural products encoded by silent gene clusters

NATURAL PRODUCTS – small molecules produced by organisms to interact with and respond to their environment

SILENT GENE CLUSTERS – gene clusters that are inactive under standard laboratory conditions

To address this need, Professor Mohammad (Mo) Seyedsayamdost, a professor of chemistry and molecular biology at Princeton University, has been investigating important substances called ‘natural products’. “These are small organic molecules produced by living organisms that are released into the environment where they carry out a number of functions, including communication and competition with other organisms,” Mo explains. For example, natural products are used by bacteria to acquire nutrients, send signals to other microbes, and defend against competitors and predators in microbial warfare.

WHY ARE NATURAL PRODUCTS IMPORTANT?

For humans, natural products have provided a tremendous source of pharmaceutical drugs. “Over 70% of our current clinical antibiotics are based on this group of molecules as well as more than half of all Food and Drug Administration-approved drugs in the past 40 years,” says Mo. “Studying and discovering new natural products, therefore, can provide new drugs and therapeutically useful molecules.” Commonly used antibiotics like vancomycin and erythromycin are examples of how bacterial natural products have proved invaluable in a clinical setting.

Infectious diseases are one of the greatest threats to global health. The massive impact of the COVID-19 pandemic is a stark case in point. When it comes to treating bacterial infections, we rely on antibiotic drugs which kill or stop the growth of disease-causing bacteria. Alexander Fleming discovered the first natural antibiotic, penicillin, in 1928, sparking an age of antibiotic discovery which radically changed modern medicine. However,

the development of antibiotics peaked in the early 1960s and has been steadily declining ever since. At the same time, cases of antibiotic resistance are rising around the world, as bacteria are evolving adaptations that increase their survival in the presence of antibiotics. Bacteria that are antibiotic resistant are becoming harder to treat, so the discovery of new antibiotics is more urgent than ever before.



PROFESSOR MOHAMMAD SEYEDSAYAMDOST

Professor of Chemistry and Molecular Biology, Princeton University, USA

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FIELD OF RESEARCH

Chemical Microbiology

.....

RESEARCH PROJECT

Investigating bacterial natural products to discover novel antibiotics

.....

FUNDERS

National Institutes of Health (NIH),
Pew Biomedical Scholars Program,
Searle Scholars Program, Burroughs
Wellcome Fund

However, the vast majority of natural products remain undiscovered. Bacteria have dedicated groups of genes called biosynthetic gene clusters, which are responsible for generating natural products. Recent research has revealed that only around 10% of these gene clusters are active under standard laboratory growth conditions, meaning there is an extensive reservoir of natural products that we have barely tapped into. These inactive gene clusters are described as ‘silent’. Since natural products are such an important source of drugs, finding ways to turn these silent gene clusters ‘on’ would have a profound impact on antibiotic discovery. This is exactly what Mo’s research group has succeeded in doing.

HOW IS MO INVESTIGATING NATURAL PRODUCTS?

Usually, when bacteria are experimented with in a lab, they are grown in a nutrient-rich medium where there are no competitors or predators. However, this does not reflect the bacteria’s natural environment, which is much more complex and dynamic in terms of microbial life. “For example, one gram of soil, the source of many of the strains we study, harbours over 10,000 species of bacteria,” Mo explains. In the wild, bacteria are bombarded

with signals and toxins from surrounding microbes, triggering them to make full use of the arsenal of natural products at their disposal so they can compete in this environment. In standard lab conditions, however, bacteria do not have the same incentive to produce as many natural products. “Behaviours that may occur naturally in a competitive, nutrient-limited context are therefore not replicated in the lab, which is why many genes stay silent in lab experiments,” says Mo.

Mo’s research team has developed a method called HiTES (High-Throughput Elicitor Screening) to trigger bacteria to produce more natural products in the lab. By exposing bacteria to molecules they would encounter in the wild, HiTES activates biosynthetic gene clusters to generate natural products that would otherwise be ‘cryptic’, or not produced, in a competitor-free environment.

But how can they tell if a silent gene cluster has been activated? In one experiment, Mo tagged bacteria with a synthetic gene which caused the bacteria to turn fluorescent green when the silent gene cluster was activated. Then, the natural product produced by the activated gene cluster could be identified and isolated.

THE RESULTS SO FAR

Using HiTES, Mo’s team has accessed over 100 new, cryptic natural products. Some of these have proven more effective than current clinical antibiotics and so provide very promising drug leads for future antibiotic development. “One cryptic natural product that we have identified is 5-fold more potent than metronidazole, the current drug used against *C. difficile* infections,” says Mo. “Another proved 20-fold more potent than ribavirin, the standard medication used against RSV, which causes a type of respiratory infection.” Interestingly, Mo found that the molecules most effective at triggering new natural products from bacteria were current antibiotics when administered at low doses. This means that old antibiotics can be used to find new cryptic ones.

These results set the stage for understanding how and why biosynthetic gene clusters are activated and opens the door to accessing a wealth of new bacterial natural products. Antibiotic resistance remains one of the greatest threats to global health, but this research and its potential to revive a new age of antibiotic discovery makes an important step towards combatting this crisis.

ABOUT CHEMICAL MICROBIOLOGY

Chemical microbiology is the study of the chemicals and chemical reactions involved in the biological processes that occur in microorganisms. In today's global health climate, this field is more relevant than ever. Chemical microbiology has informed our ongoing efforts to combat COVID-19, providing scientists with a deeper understanding of viruses and the development of vaccines and antiviral drugs. While COVID-19 poses an immediate health challenge, the creeping threat of antibiotic resistance seriously endangers modern medicine and will have devastating consequences unless we find innovative solutions. Mo's research into antibiotic natural products is a great illustration of how valuable chemical microbiology can be in tackling the problems of infectious diseases.

THE MICROBES WITHIN US

While drug development is a significant focus of chemical microbiology, the field has wide-ranging potential. Most microbes we come into contact with do not cause disease. For example, did you know that approximately

39 trillion microbes live inside the human body? The microbial communities inside us, primarily residing in the gut, are known as the human microbiome, which in recent years has emerged as a new frontier for understanding human health. The composition of our microbiomes has been linked to many conditions, from obesity to anxiety. Increasing our understanding of chemical reactions in the gut is just one other example of how chemical microbiology is being applied to develop novel therapeutic techniques.

THE IMPORTANCE OF INTERDISCIPLINARY RESEARCH

Chemical microbiology is a highly interdisciplinary research area, combining microbiology, genetics, biochemistry and organic chemistry (the branch of chemistry that deals with carbon-containing molecules). "Chemical microbiologists need to be generalists and specialists at the same time," says Mo. Consider his work on natural products. This research requires expertise in the analysis of genomes and biosynthetic gene

clusters, biochemical methods to isolate natural products and uncover biosynthetic pathways, and, finally, genetic and microbiological techniques for determining natural product functions. "In my mind, these various approaches go hand-in-hand as they reveal the full complexity, the different layers that underlie each single natural product," says Mo.

WHERE COULD A CAREER IN CHEMICAL MICROBIOLOGY LEAD YOU?

It is common for chemical microbiologists to work in academia. You could work in or lead a university research lab, conducting scientific research and publishing your findings in academic journals. Chemical microbiologists also work for biotechnology and pharmaceutical companies, where the science of chemical microbiology is applied to the manufacturing of drugs. Working in industry may involve responsibilities such as data collection and analysis, managing lab operations and presenting findings to medical professionals.

EXPLORE CAREERS IN CHEMICAL MICROBIOLOGY

- Look out for relevant outreach schemes for young people in your area, such as talks or work experience opportunities. Mo's department (www.chemistry.princeton.edu/diversity-inclusion/outreach) offers chemistry workshops, with experiments led by members of his research group, as well as the 'Biochemistry Outreach Symposium', an annual summer event targeted at high school students.
- Keep up to date with developments in the field by reading publications and attending events. Mo recommends the American Chemical Society (www.acs.org/content/acs/en.html) and American Society for Microbiology (www.asm.org) which offer great workshops, symposia and annual conferences.
- The ACS recently published an entire special issue (pubs.acs.org/toc/acbcct/15/5) dedicated to highlighting the latest discoveries in chemical microbiology. Have a read to explore the kind of research you could be doing as a chemical microbiologist.

MO'S TOP TIPS

- 01 Pursue your passion and carve your own path.
- 02 Embrace the unpredictability of research! Not knowing the answer going into a project and then finally uncovering it is what makes research exhilarating.

PATHWAY FROM SCHOOL TO CHEMICAL MICROBIOLOGY

- Mo recommends taking chemistry and biology at school, as research in chemical microbiology requires a solid foundation in both subjects.
- Higher education is necessary for a career in chemical microbiology. Universities generally do not offer undergraduate courses dedicated to chemical microbiology, so studying related fields such as microbiology, biochemistry, chemistry or biology are all possible routes. From there, you can specialise in chemical microbiology further down the line. Mo only narrowed down his field of study to the chemical microbiology of natural products after completing his PhD.



HOW DID MO BECOME A CHEMICAL MICROBIOLOGIST?

WHAT WERE YOUR INTERESTS WHEN YOU WERE YOUNGER?

I wanted to be a professional athlete when I was young. My parents had other ideas and gently nudged me onto the path that I'm on today. I entered college with a pre-medical track in mind, but then fell in love with organic chemistry and biochemistry.

WHO INSPIRED YOU TO BECOME A SCIENTIST?

The courses I took with Professor Phil Keehn (organic chemistry), Professor Melissa Moore (biochemistry) and Professor Liz Hedstrom

(enzymology) were especially influential. I then joined Professor Hedstrom's lab to conduct undergraduate research and fell in love with lab work and scientific research. My graduate and postdoctoral advisers (Professors JoAnne Stubbe, Jon Clardy and Roberto Kolter) were also fantastic mentors and role models and very supportive of my career.

HOW HAS YOUR CAREER PATHWAY LED YOU TO YOUR CURRENT RESEARCH?

During my undergraduate and graduate research, I focused on detailed mechanistic

studies of important enzymes, which gave me a strong foundation in mechanistic biochemistry and enzymology. As a postdoc, I was introduced to the wonderful world of microbiology and natural products. In my independent career, I have combined these different approaches with the goal of obtaining a comprehensive, holistic understanding of microbial chemistry and natural products.

WHAT DO YOU ENJOY DOING OUTSIDE WORK?

Sports! Tennis, soccer and basketball – though there is not a whole lot of time outside of work.



Mo's lab group at Princeton University

● FIELDS AND FUNGICIDES: MIXING MICROBIOLOGY AND SOCIAL SCIENCE

FARMERS OFTEN USE FUNGICIDES TO PROTECT THEIR CROPS FROM FUNGAL DISEASES. HOWEVER, THERE ARE WORRIES THAT THESE FUNGICIDES CAN DAMAGE THE ENVIRONMENT IF THEY LEAK INTO WATER SOURCES AND MAY EVEN BUILD ANTIMICROBIAL RESISTANCE AGAINST TREATMENTS FOR HUMAN DISEASES. A UNIQUE TEAM OF EARLY-CAREER RESEARCHERS FROM THE UNIVERSITY OF EXETER AND THE UNIVERSITY OF BRISTOL IN THE UK IS ADDRESSING THIS CONCERN THROUGH ENVIRONMENTAL TESTS AND DIRECT ENGAGEMENT WITH FARMERS

GLOSSARY

AGRONOMIST – an expert in the science of soil management and crop production

ANTIBIOTIC – any compound that combats or destroys bacterial microbes

ANTIMICROBIAL RESISTANCE – the ability of microorganisms to withstand antimicrobial treatments

AZOLE – a group of chemical compounds often used as agricultural or medicinal fungicides

FUNGI – an organism that has no chlorophyll and must live in or on plants, animals or decaying material (e.g., mould, mildew or mushrooms)

FUNGICIDE/ANTIFUNGAL – a group of antimicrobials that specifically combats or destroys fungal microbes

PATHOGEN – a disease-causing organism, such as some bacteria, viruses, or fungi

RUNOFF – the draining away of substances from land into water sources

A meeting at a training event about antimicrobial resistance led to a diverse group of early-career researchers realising that their skillsets could be combined to investigate an underexplored issue. “We come from a variety of backgrounds including microbiology, human geography and theology,” says Dr Andy Jones, the theologian in the group. While biologists in the team have experience in researching antimicrobial resistance in fungi, the social scientists have experience of working and collaborating with farmers. Together, they investigated how fungicide use in agriculture could potentially lead to antimicrobial resistance in human diseases.

The team’s project involved collecting and analysing water samples from eight river sites in south-west England, conducting interviews with farmers and developing a network of stakeholders in the region. The team involved farmers and their viewpoints at every stage. “We wanted our research to develop from our discussions with farmers and stakeholders,” says Andy. “For instance, they helped us identify locations for prospective water samples and select fungicides to test for.”

THE RISKS OF FUNGICIDES

Any biological or chemical compound that kills fungi is a fungicide. “Our research focuses on chemical fungicides called azoles,” says Andy. “We suspected that fungicides used for arable farming were making their way into nearby water bodies.” If fungicides linger in

the local environment, they have the potential to make fungal species more resistant to those fungicides. “Treatments for human fungal infections are derived from the same class of fungicides that are used in arable farming, so resistance to fungicides in arable farming might lead to resistance to antifungal treatments in humans,” explains Andy.

Antimicrobial resistance is an emerging issue around the world. Some antibiotic-resistant pathogens, such as Methicillin-resistant *Staphylococcus aureus* (MRSA), develop in hospitals as a result of extensive use of antibiotics in humans. Elsewhere, the overuse of antibiotics to treat or protect livestock from disease can lead to similar outcomes. It is believed that the overuse of antifungals on crops also presents a risk, but while there has been research into antibiotic resistance emerging from the meat industry, antifungal resistance associated with fungicide runoff from arable farming into surface waters is comparatively underexplored. “The threat is serious as we have a limited arsenal of antifungals to treat fungal infections in humans,” says microbiologist Dr Dhara Malavia. “If our antifungals become useless, it could increase mortality from infections that would otherwise have been treated.”

The microbiologists on the team analysed water samples from eight river sites adjacent to fields where fungicides were applied.



“Because of the COVID-19 pandemic, we were unable to gather samples immediately after fungicide application,” says Andy. “We eventually took our samples many months after the chemicals were applied and we still detected fungicides in every sample.” This indicates that these chemicals remain in the environment, rather than breaking down, which creates an environment where fungi are more likely to develop resistance.

THE IMPORTANCE OF SOCIAL SCIENCE

While microbiology is needed to understand how fungicides affect the environment, it is also important to understand why fungicides are used. “We have to consider farmers’ motivators from a social science perspective,” says human geographer Dr Ray Chan. The social scientists in the team worked with a group called Innovation for Agriculture that connects farmers with academic researchers. The scientists spent time getting to know farmers in the research area, understanding their points of view and learning about the economic pressures they experience.

“It’s important to understand the history of fungicide use on a farm, as well as the relationships farmers have with external advisers such as agronomists, and how these relationships influence decisions to use fungicides,” says human geographer Dr Susan Conlon. “Social science methods, such as interviewing and participant observation, are necessary to explore these questions and allow farmers to communicate their opinions and experiences.” This inclusivity is necessary to build trust between researchers and farmers and affects how seriously farmers take any recommendations the research provides.

“There doesn’t seem to be consensus amongst farmers regarding fungicide use,” says Andy. “While some farmers are concerned about environmental sustainability and have reduced chemical use to increase soil health, others continue to use chemicals to ensure consistent crop yields and economic returns.” Agricultural practices are changing as an increasing number of farmers experience decreases in their soil quality

and concerns grow about future viability of crops. For instance, regenerative agriculture is a growing movement that focuses on sustainable practices developed through knowledge of ecological relationships and local qualities of the land. This tends to involve much lower levels of chemical application, including fungicides.

Additionally, the team uncovered interesting relationships between farmers and other stakeholders. “Farmers often pay agronomists to advise them on what chemicals they need to apply to their crops,” says Andy. “This exposes an interesting dynamic of trust between farmers and agronomists.” Given that agronomists are often employed by the companies that develop fungicides, some farmers reported suspicions that the agronomists may over-estimate the quantity of fungicide needed to protect their crops, but farmers also expect agronomists to secure consistent crop yields for them each harvest.

COLLABORATION

“Our collaboration has encouraged us to think about the ways social, biological and political issues intersect,” says Andy. The team was invited to attend the Groundswell farming festival, which proved invaluable for learning about the issues that concern farmers, and how agricultural techniques are changing and evolving, including emerging movements such as regenerative agriculture.

As with any collaboration, there were barriers to overcome. Different specialisms use different ‘languages’, so finding ways to communicate across disciplines, without relying on specialist terms, provided another learning opportunity for everyone involved.

NEXT STEPS

“We are looking to expand on our findings by taking a larger number of water samples over a longer period,” says Andy. The team is interested in whether fungicide concentrations in water bodies fluctuate throughout the year, and to what extent this relates to farmers’ applications of fungicides. The team also wants to dig deeper into the relationships between farmers and agronomists, and how

DR SUSAN CONLON

Human Geography, University of Bristol (CABOT), UK

FUNDER: Cabot Institute for the Environment



DR RAY CHAN

Human Geography, University of Exeter, UK

FUNDERS: UK Research and Innovation (UKRI), The Wellcome Trust, EU Cost Network



DR ANDY JONES

Theology and Philosophy, University of Exeter, UK

FUNDER: John Templeton Foundation



DR DHARA MALAVIA

Molecular Microbiology, University of Exeter, UK

FUNDERS: Wellcome Trust, Cabot Innovation Fund



DR AIMEE MURRAY

Microbiology, University of Exeter, UK

FUNDERS: Natural Environment Research Council (NERC), Biotechnology and Biological Sciences Research Council (BBSRC)



JOINT RESEARCH PROJECT

Understanding fungicide use in food crops in Bristol and Devon in the UK

such relationships can be nurtured to ensure the best outcomes for all, including the environment and wider society.

The team will bring together representatives from farming associations, water companies and agronomic organisations as part of a steering committee, making recommendations to policy makers. The researchers will also disseminate their findings through online workshops and articles for the wider research community, highlighting the risks of antimicrobial resistance as well as the pressures farmers face. “Our mix of disciplines is unusual, but there is growing interest from universities to promote these kinds of collaborative projects,” says Andy. “Academic disciplines can too easily become isolated from one another, which can create a barrier for solving problems effectively and communicating research outcomes.”

ABOUT MICROBIOLOGY

Microbiology involves the study of microbes – any living organism too small to be seen by the unaided eye. Microbes include bacteria, viruses and many species of fungi. Dr Dhara Malavia and Dr Aimee Murray run the microbiology component of this research project.

Dhara and Aimee collected and analysed water samples from eight river sites in the project area. As the project progresses, they aim to expand their work to take a closer look at the interactions between fungicides and local microbial populations. “We are aiming to do local environmental risk assessments to determine if azoles found in waters surrounding farms might be negatively impacting local ecosystems and if azoles could increase levels of resistance,” explains Aimee.

Dhara and Aimee’s findings will only be useful if they can be communicated effectively. “Our conclusions will be useful as a talking point

with farmers, to understand their practices and communicate how these may be affecting their local environment,” says Aimee. “It might also be of interest to policy makers, as part of the evidence they would use to decide whether new legislation is needed to limit azole application.”

Dhara and Aimee use a technique called high-performance liquid chromatography, which is a powerful method of separating, identifying and quantifying the chemical compounds of a particular mixture. “Since the technique offers high sensitivity, it is ideal for detection of small quantities of azoles found in water samples,” says Dhara. “Using this technique, we have detected four different agricultural azoles in collected water samples, with one in particular present in almost every sample.”

To assess whether or not these azoles present a risk, Dhara and Aimee set ‘thresholds’ that define the concentration at which azoles are

considered dangerous for environmental or human health. Setting these involves consulting pre-existing scientific literature alongside their own research. “Pre-published data covers the effects of azoles on key elements of the ecosystem such as algae or freshwater invertebrates,” says Aimee. “Our data is generated using a new experimental tool called the SELECT method which finds the lowest concentration of the azole that is likely to increase resistance.”

“STEM scientists and social scientists communicate differently to some extent!” says Aimee. “This means it can sometimes be a challenge to understand or be fully understood. We benefit from learning about social science approaches and knowing that our research will reach the relevant people.”

EXPLORE CAREERS IN MICROBIOLOGY

- The Royal Society of Biology provides career resources for students: www.rsb.org.uk/careers-and-cpd/careers/career-resources
- The Microbiology Society provides advice about degrees and apprenticeships: www.microbiologysociety.org/careers/information-for-school-leavers.html
- Aimee recommends seeking lab experience. The BioGrad course is one way to achieve this, and it offers some means-tested bursaries: www.biograd.co.uk/laboratory-skills-and-microbiology.php
- Salaries for microbiologists in the UK vary. For instance, microbiologists are employed by the NHS at salaries starting at around £32,000. More information can be found here: www.prospects.ac.uk/job-profiles/microbiologist

PATHWAY FROM SCHOOL TO MICROBIOLOGY

Aimee recommends taking biology, chemistry, maths and, if possible, English at college. She suggests university courses in biology or microbiology as straightforward pathways into a career in microbiology.



MEET DHARA



@dr_malavia

I am one of the leads on the project and focus on the detection and quantification of fungicides within field samples. As a fungal microbiologist, I bring expertise on the effects and consequences of fungicides in agriculture.

I have always been interested in understanding how harmful fungi become resistant to antifungals, and several of my projects have focused on exploring this. A continued curiosity to identify previously unknown and overlooked factors driving resistance in fungi led me to this project.

Although I had changing interests and career ideas, I realised I was passionate about

biology from a very young age. I became more determined to pursue microbiology when I first looked through a microscope and saw numerous stained purple and pink microbes. It was the first time I saw life in a different light, and I was curious to understand how life behaves at the cellular level.

One of the benefits of working as a scientist is that one can experience many eureka moments. I've experienced one every time I've identified a novel gene and its function in cellular processes.

Nature inspires me. My work has taught me to make scientific and unbiased observations

about the microbial organisms of the natural world; it brings me closer to nature. Determination, persistence and patience make me successful. One of my proudest achievements is securing and successfully completing my PhD.

My ambition is to continue working as a research scientist. I hope that I will have the opportunity to work on a variety of projects, ranging from medical to environmental microbiology. I would love an opportunity to explore, identify and mitigate causes of drug resistance in environmental microbes, alongside driving change in human activities that damage the environment.

MEET AIMEE



@AimeeKMurray

I work on the environmental risk assessment part of the project, including highlighting our work to relevant policy makers.

My PhD was co-funded by AstraZeneca, the pharmaceutical company, which really made me look at my research from a new angle. I was then able to win fellowship funding to carry on my PhD research, which led me to meet the rest of the team at an early-career researcher's networking event.

When I was younger, I thought I might like to be a writer or a judge. At school, I liked biology, but also English and foreign languages. I wanted to be in a rock band for a while! In the end, I took a biology undergraduate degree. It wasn't until then that I realised how amazing microbiology is, so I specialised in that as much

as I could. I didn't know what I wanted to do until my final year at university, when I did a lab project on MRSA that made me interested in doing research.

I've made some interesting discoveries, and everything is a culmination of lots of little pieces of progress that have added up over time, with support and input from many different people.

I'm motivated by two things: answering questions and making a difference. I've always been curious about a lot of things. My work lets me ask and answer my own questions, which is challenging but satisfying. Our work with businesses, different industries and policymakers helps me make those questions and answers useful to society.

As a scientist, it's important to be determined, curious and persistent. And it's always worth trying for opportunities, even if you don't think you stand a chance. I was the first person from my family to go to university, let alone get a PhD. A recent career highlight was being invited to present my research to the All-Party Parliamentary Group on Antibiotics and talking to MPs and members of the House of Lords about how it could make a difference.

I will continue to work on antimicrobial resistance in the environment. I'm interested in whether compounds other than antibiotics can increase antimicrobial resistance. I'm also keen to start exploring more fundamental questions about antimicrobial resistance evolution.

ABOUT SOCIAL SCIENCE

Social science encompasses a broad range of disciplines focusing on how people behave in society and what drives their behaviour.

Dr Susan Conlon and Dr Ray Chan both specialise in human geography, while Dr Andy Jones specialises in philosophy and theology.

Susan, Ray and Andy were responsible for engaging with farmers and other stakeholders,

to understand what led the farmers to make the choices that they did regarding fungicide use. "We adopted an interview method to understand how farmers perceive their use of azoles and the challenges they face in attempting to reduce it," explains Ray.

Social scientists help close the gap between hard data and their real-world application.

"Our methods help microbiologists understand the social-cultural perceptions and barriers to behaviour change in azole use in everyday farming," says Ray. "Combining microbiology and social science enables a more holistic understanding."

"We find opportunities for researchers to engage with public and private stakeholders," says Ray. Susan highlights the solidarity built through collaboration. "We have benefited from working with open-minded researchers who are receptive to learning about new

approaches and methods, and taking risks together," she says.

Developing interdisciplinary projects is rarely a simple procedure. "The process is time-consuming and requires leadership and sustained team effort to ensure effective communications, mutual understanding and equal treatment of disciplines," explains Susan. Ray adds, "Avoiding technical jargon steers us towards simpler, more effective language during group discussions."

EXPLORE CAREERS IN SOCIAL SCIENCE

- The Royal Geographic Society offers career advice and information: www.rgs.org/geography/choose-geography/careers

- The Open University has a similar range of resources: www.help.open.ac.uk/career-opportunities-social-science

- Susan recommends learning more about what the social sciences are. The UK Research and Innovation (UKRI) provides a useful starting point: www.esrc.ukri.org/about-us/what-is-social-science/social-science-disciplines

PATHWAY FROM SCHOOL TO SOCIAL SCIENCE

Ray recommends subjects such as geography, sociology, psychology, anthropology and political science to provide the foundation for a career in social science.

MEET ANDY



 @andyjonesphd

In my previous research, I investigated the importance of metaphors for understanding science. Scientists rarely think about how society and language frame how scientific research is conducted. I highlight these factors with the aim of making our research relevant for society.

I was not academic growing up. I didn't know what philosophy was until I went to college, and I hadn't planned to go to university until I was inspired by a lecture on whether free will exists! You don't necessarily need a clear sense of your career – in many cases, unpredictable opportunities will arise that will be significant for your life. Be open to them.

A philosopher once said that all philosophy

is just a footnote to Plato. Reflecting on how projects develop is more important than your results. I am continually learning about my own research practices and further questions to explore.

I'm inspired by drawing people together from various specialisms to develop new research questions. I focus on identifying cases where philosophy and theology can bring new perspectives. In another project, I am working with physicists to consider how ethics matter for nuclear industries.

My communication skills have been an asset. I thrive when talking with people from different subjects and collaborating to resolve issues.

Previously working in the charity sector, I learnt how to approach people without judgement.

I am the only person in my family to have completed a PhD, so this was a very proud moment for me and my family. Recently, I submitted my first book for publication, exploring how the philosopher Immanuel Kant influenced the development of biology in the British Isles.

I am continuing working on interdisciplinary projects. I have recently started a job with the school of education at Exeter University, supporting various research projects to manage their stakeholders. I am also supporting the development of a new research centre studying authoritarian regimes.

MEET SUSAN



@SusanConlon83

I led the initial administration of the project, conducting interviews and informal conversations with stakeholders, as well as coordinating the ethical approval needed from the university to start interviews.

I'm interested in understanding how and why people interact with the natural environment, especially water, to support their livelihoods, in contexts where people are often under pressure to change their practices due to new government policies. To this project, I brought my understanding of the complexities that people face in changing their water use and my experience of social science data collection.

I didn't know I wanted to pursue a career in human geography. I grew up in rural Ireland

and was really involved in my local community as a kid, especially in sports and music. I was always curious about visiting new places and learning new languages. In my late 20s, I became particularly interested in what makes people change their views and actions in relation to the environment.

I am particularly motivated by the interconnectedness of the global challenges we face in relation to the environment and development, and how we can learn from different experiences of similar issues across the globe.

I try to be as open-minded and compassionate as I can be, to have courage to have challenging conversations and to be honest about not

knowing a great deal! I am inspired by people who recognise diversity, try their best to adopt a growth mindset, and promote work-life balance.

Making the transition from the private sector to academic research and making wonderful friendships and collaborations along the way have been the proudest moments in my career, so far.

I would love to continue learning about the socio-cultural and political challenges we face in maintaining access to safe and healthy water supply, either within or outside of academia.

MEET RAY



@RayChanKW1

My research approach combines social science and scientific knowledge. My experience is beneficial for conducting in-depth interviews with different stakeholders, and for scrutinising farming-specific antimicrobial management strategies.

I have worked with interdisciplinary researchers to examine the reduction of antibiotic use in farm animals in China and the UK. I collaborate with biologists, philosophers and computer scientists to explore to reduce the use of azoles in arable farming.

My concern with antimicrobial resistance stems from growing up on a farm in Hong Kong. This inspired my early research on understanding how

farmers in China manage animal health using antimicrobials. This drove me to become a human geographer, to understand the interactions between humans, animals and diseases.

Being awarded a prestigious Wellcome Trust research grant and seeing my students pursue careers in social science research are highlights for me.

Concepts from human geography inspire me to learn new ways of seeing the world, especially in understanding the relationships between people, animals, nature and places within a particular social context.

Three key values have led to my success.

Perseverance, for striving to find ways to tackle challenges that arise in the researcher's journey, integrity for upholding ethical standards when conducting research, and passion to keep learning.

I want to become a leading expert in digital farming and antimicrobial resistance within food production in the UK and China. I plan to develop an interdisciplinary research team of social and STEM scientists to forge new collaborations to tackle the global challenges of antimicrobial resistance.

THE TEAM'S TOP TIPS

- 01 Be persistent.** Never let failure demotivate you – it is the first step towards success.
- 02** If you have a strong idea of what you want to do, **set targets** for your career objectives, and **persevere** if things don't go to plan.
- 03** **Share your visions and aspirations** with those around you. Make connections with people working in the field you want to join.



FLIGHTS OF FANCY: CAN WE UNRAVEL THE MYSTERY OF FLIGHT?

CHARLES DARWIN'S THEORY OF NATURAL SELECTION IS ONE OF THE MOST IMPORTANT AND GROUND-BREAKING SCIENTIFIC CONCEPTS EVER CONSTRUCTED. EVEN SO, THERE ARE SOME ASPECTS OF EVOLUTION THAT SCIENTISTS ARE STILL TRYING TO UNDERSTAND. DR ASHLEY HEERS FROM CALIFORNIA STATE UNIVERSITY IN LOS ANGELES, USA, IS STUDYING JUVENILE BIRDS TO UNRAVEL ONE SUCH MYSTERY THAT HAS HAD EVOLUTIONARY BIOLOGISTS PUZZLED FOR DECADES: THE EVOLUTION OF FLIGHT

TALK LIKE AN EVOLUTIONARY BIOLOGIST

NATURAL SELECTION – the process of adaptation in which traits that give an organism an advantage persist from generation to generation. This is one of the main drivers of evolution

RUDIMENTARY FEATURES – underdeveloped body parts that are incapable of performing functions to the same degree that their fully-developed counterparts can

LOCOMOTOR STRUCTURES – parts of an animal's body that help it move around

MUSCULOSKELETAL MODELS – digital models that help scientists understand how an animal's bones and muscles work together to produce movement

states that species evolve through incremental, beneficial changes that accumulate over incredibly lengthy periods. In this way, fins evolved into legs, eyespots evolved into eyes, and the front limbs of certain dinosaurs evolved into the wings of modern-day birds.

One problem with the theory that scientists have had trouble solving is the dilemma of rudimentary stages. This dilemma arises because some highly specialised structures, such as wings, only seem to perform their function when they are fully formed. According to the theory of natural selection, wings would have had to start out as small, underdeveloped 'proto-wings' that could not have been capable of producing flight. So, what function did these 'proto-wings' have? What were they 'selected' for, and how did they evolve into the fully formed wings that allow birds to fly?

Or, as Mivart first asked in 1871, "What use is 'half a wing'?" Based at California State University, Dr Ashley Heers is an evolutionary biologist whose work involves unravelling this mystery to explore a dilemma that has challenged scientists in her field since Darwin first posed his theory.

WHAT ARE RUDIMENTARY LOCOMOTOR STRUCTURES?

Much of Ashley's work involves studying the form and function of rudimentary locomotor structures found in birds. These are body parts that a bird uses for moving around but that are smaller or less developed than equivalent body parts in other closely related animals. For example, a juvenile bird's wings are much less developed than the wings of an adult bird. They are smaller, with less effective feathers and smaller wing muscles anchored to less robust bones.

Rudimentary locomotor structures can also be found in adult birds of some species. Flightless birds, such as some steamer ducks, have lost the ability to fly during their evolutionary history. As a result, they have wings that are incapable of flight but that are still able to perform other functions, such as swimming.

Even fossil records contain traces of rudimentary structures. For example, the extinct predecessors of birds – a subset of theropod dinosaurs – had small, feathered forelimbs with less robust bones than modern-day birds.

Charles Darwin proposed his ground-breaking theory of natural selection over 150 years ago, but to this day, scientists are still grappling with some of the theory's intricacies. The theory



Ashley explains, “In this case, immature birds are developing the ability to fly and extinct dinosaurs were evolving the ability to fly, so both sets of animals have rudimentary or ‘transitional’ locomotor structures.” Understanding how these rudimentary structures develop and help juvenile birds to move around may provide insight into their evolutionary history, from appendages that were not used for locomotion to fully formed wings capable of flight.

HOW DOES ASHLEY STUDY THESE STRUCTURES?

“I use many techniques in my research,” explains Ashley, “because each provides a different type of information.” She uses photographs and microscopes to examine the structure of feathers and wings, dissections to determine the sizes of muscles and their configurations, and CT or laser scans to create 3D bone models to study how bones change in shape and size during development.

Ashley also needs to understand how these body parts function. By combining X-ray and high-speed videos with other techniques, she can measure movement and performance and create digital models of the birds she is studying. This allows her to assess how bones, muscles and feathers work together when juvenile and adult birds are moving in particular ways.

This technique is called musculoskeletal modelling and it can get very complex but is, essentially, a four-step process. The first step involves taking a CT or laser scan of the bird to visualise its bones and construct a digital model of its skeleton. Secondly, a dissection is performed to measure muscles and understand how they attach to the skeleton so that they can be added to the digital model. The third step is to use X-ray videos to see how birds move their bones when flapping their wings, and add these movements to the model. Finally, the force produced by the bird while flapping is added to the model.

With a complete model, Ashley can run simulations of the bird’s movements to understand how the bones and muscles work together and how much force or power may need to be produced. “One of the great things about musculoskeletal models,” says Ashley, “is that we can change things in our model that we can’t change in a real bird – like wing or muscle size, muscle attachments or flapping movements – which allows us to see how those variables affect performance.”

WHAT CAN WE LEARN FROM THESE MODELS?

Working with live birds and these models, Ashley and her colleagues, including Ken Dial, Bret Tobalske, Brandon Jackson and Terry Dial, have shown that juvenile birds use their underdeveloped wings to help improve



DR ASHLEY HEERS
California State University, Los Angeles,
USA

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FIELD OF RESEARCH
Evolutionary Biology

.....

RESEARCH PROJECT
Examining the wing movements of young birds to explore the development and evolution of bird flight

.....

FUNDER
US National Science Foundation (NSF)

the performance of their legs. For example, young birds flap their wings to help them run up steep inclines or to slow their descent on the way back down. They also use their wings to help them jump higher and swim faster. As the birds grow and become stronger, their wings help them to run up steeper inclines and jump higher, which eventually leads to the birds being able to fly.

Ashley says, “This is really important in terms of thinking about the evolution of flight in extinct dinosaurs, because it shows us that rudimentary structures are useful – even crucial to the survival of some animals.” In the same way that a young bird slowly develops flight as its wings grow, extinct species could have slowly evolved flight as larger and more powerful wings were acquired through the process of natural selection.

Ashley’s work has helped clarify the dilemma of rudimentary stages. Early proto-wings were able to evolve into fully formed wings because they were useful – probably for many functions but, perhaps, just not the uses scientists had expected. Having helped uphold Darwin’s theory of natural selection, Ashley is excited about her future work. She says, “Birds are extremely diverse, and in the grand scheme of things, I’ve only scratched the surface!”

ABOUT EVOLUTIONARY BIOLOGY

Evolutionary biology is the study of how life on Earth evolved. It helps scientists understand how the species on Earth presently came into existence, as well as how other species, like some dinosaurs, became extinct. Understanding how organisms develop, evolve and adapt to changes in their environments has important practical implications for fields such as ecology and conservation.

Evolutionary biology can also help us re-trace the story of life on Earth that connects all living organisms on the planet. Exploring these questions and unravelling these mysteries can help us understand humanity's place in the vast web of life.

WHAT DISCIPLINES DO EVOLUTIONARY BIOLOGISTS MAKE USE OF?

Ashley's research into the complex evolution of flight demonstrates the multidisciplinary nature of evolutionary biology. Adult birds do not just

spring into life; they develop from an embryo into a hatchling and then, finally, into an adult capable of flight. In the same way, every species on earth did not just appear; they evolved from ancestors that may now be long extinct.

"This is why I combine biology, palaeontology and engineering," says Ashley. "Biology for a developmental perspective, palaeontology for an evolutionary perspective and engineering to 'build' digital birds and assess how factors that change during development and evolution influence locomotion."

WHAT DOES A TYPICAL WORKING DAY LOOK LIKE FOR AN EVOLUTIONARY BIOLOGIST?

"That completely depends on the time of year," explains Ashley. "In the spring and summer, I often have a cohort of developing birds, so my students and I spend a lot of time taking care of them and collecting data on anatomy and performance." Later in the year, Ashley and her

team analyse these data so that they can start building models of their birds. "And between all of these activities, I teach, so sometimes it feels a bit like juggling!" she adds.

WHAT ARE THE CHALLENGES OF BEING AN EVOLUTIONARY BIOLOGIST?

"Being patient is one of the most challenging things about my job," says Ashley. "It takes an incredible amount of work to rear a cohort of birds, and, afterwards, the analyses can be challenging or at least time-consuming. But it's also very rewarding, and I love examining my final graphs because they tell my birds' stories."

PATHWAY FROM SCHOOL TO EVOLUTIONARY BIOLOGY

- Studying biology at school is important for all types of evolutionary biology.
- An understanding of palaeontology is also helpful, depending on what evolutionary scale you are interested in. MyFossil provides a list of opportunities for high-school students: www.myfossil.org/resources/field-opportunities
- Other subjects that might prove to be useful are anatomy, physiology and biomechanics.

EXPLORE CAREERS IN EVOLUTIONARY BIOLOGY

- Volunteering in a research lab is a great way to gain practical experience. Zoos, wildlife rehabilitation centres, the US Forest Service (www.fs.usda.gov) and the US Fish and Wildlife Service (www.fws.gov) all offer research placements for school students. You could also consider writing to university scientists whose work you find interesting.
- Get involved in citizen science projects. Ashley suggests The Cornell lab of Ornithology (www.birds.cornell.edu/home/get-involved), which has several ongoing projects.
- Ashley also advises expanding your hobbies. Going birdwatching and reading popular science books, such as Neil Shubin's *Your Inner Fish*, are a great way to introduce yourself to the field.
- According to several websites, the average salary for an evolutionary biologist in the US is around \$70,000 (www.indeed.com/career/salaries/Evolutionary%20Biology?from=whatwhere)



HOW DID ASHLEY BECOME AN EVOLUTIONARY BIOLOGIST?

WHAT WERE YOUR INTERESTS WHEN YOU WERE YOUNGER?

I have always loved animals, babies and books. When I was little, I was obsessed with the 'Nancy Drew' mysteries and wanted to be a 'sleuth' and, gradually, that desire morphed into scientific sleuthing. I also became interested in geology and fossils in 6th grade.

WHAT SPARKED YOUR LOVE OF BIRDS?

I wasn't especially interested in birds until I read that birds are the descendants of dinosaurs – in other words, they are living dinosaurs. The fact that I could go outside and watch a 'dinosaur' was the most amazing thing I had ever learned. I knew then that I wanted to explore the mystery of how birds evolved, and when I later found out that a similar mystery takes place during bird development, I was hooked!

HOW DID YOU COME TO STUDY BIRD LOCOMOTION AND THE EVOLUTION OF FLIGHT?

Going to college, I knew I wanted to study evolution, and I dabbled in many different areas. But I kept returning to the evolution of bird flight, partially because I love animals, and partially because I love mysteries and I wanted to know how birds became so unique.

When I was working on my senior thesis, it became obvious to me that I didn't understand how living birds 'work'. How could I interpret the anatomy of fossils if I didn't know how anatomy and locomotion are linked in living birds? So, I joined Ken Dial's Flight Laboratory at the University of Montana, where the first studies exploring how baby birds utilise their wings were conducted. UM Flight Lab's resources, facilities and personnel allowed me to follow my passion: babies, birds, dinosaurs and evolution... and I'm still doing that!

DO YOU HAVE ANY STANDOUT MEMORIES FROM YOUR TIME WORKING WITH LIVE BIRDS?

Some of my favourite memories are of my birds expressing their personalities. In graduate school, I started with chukar partridges, and I'd always wear a sweatshirt when working with them because the chicks liked sleeping in my pockets. Later I got peafowl, and the juveniles would play tug-a-war with feathers and chase each other around their pen in what appeared to be a game of tag. Before working with birds, I had no idea that they had such personalities.

WHAT ARE YOUR AMBITIONS FOR THE FUTURE?

Compiling my PhD thesis was thrilling and I'm still working on developing that story, so

I want to continue working with birds with rudimentary wings. I would also like to expand into other animal groups with rudimentary structures, and I want to write books and maybe even help animate a film.

WHAT IS YOUR FAVOURITE FACT ABOUT BIRDS?

I think my favourite thing about birds is how versatile they are. They can use their wings and legs either independently or together, and this versatility yields amazing variations in locomotion, development, foraging styles, habitat preferences, etc. Some birds are very specialised, and others are jacks of all trades that can fly through the air, walk on land and swim underwater – no other vertebrate can do those things.

WHAT DO YOU ENJOY DOING IN YOUR FREE TIME?

I love to read. I also enjoy being outside (hiking, camping, etc.), trying different types of exercise like barre (which combines ballet and yoga), DIY projects, travelling and visiting family. My nieces and nephews are some of my favourite people, and we have a lot of fun exploring and birdwatching (although we're still working on which way the binoculars are supposed to face).

ASHLEY'S TOP TIPS

- 01 Be curious and open-minded.
- 02 Go outside and observe your animals, and read, read, read about them!
- 03 At university, find a good academic 'family' that will support you both scientifically and emotionally.

UNDERSTANDING ERUPTIONS: HOW CAN WE DETERMINE WHICH VOLCANOES POSE THE GREATEST THREAT?

FOR MILLENNIA, HUMANS HAVE LOOKED UPON VOLCANOES WITH A SENSE OF AWE AND TERROR. NOWADAYS, WE HAVE A MUCH DEEPER UNDERSTANDING OF WHAT VOLCANOES ARE AND HOW THEY WORK. HOWEVER, PREDICTING WHEN AND WHERE AN ERUPTION IS GOING TO OCCUR IS STILL A CHALLENGE. DR MICHAEL EDDY, A GEOLOGIST FROM PURDUE UNIVERSITY IN INDIANA, USA, IS RESEARCHING HOW TO MAKE MORE ACCURATE PREDICTIONS ABOUT WHERE THE MOST VIOLENT ERUPTIONS ARE LIKELY TO HAPPEN

TALK LIKE A GEOLOGIST

PYROCLASTIC FLOW - a fast-moving mass of hot ash, gases and rock fragments

MAGMA - extremely hot liquid rock found under the Earth's surface. When it breaks through the surface in a volcanic eruption, it is known as lava

RHYOLITE MAGMA - a type of magma that has a very high silica content. When it cools, it hardens and becomes a kind of volcanic rock known as rhyolite

COMPACTION - a process in which granular materials are forced together by pressure from above, forcing any liquid

between the granules to be expelled

VISCOSITY - a measure of how easily a substance flows. Substances with high viscosities are sticky and flow very slowly

RADIOACTIVE ISOTOPE - an unstable form of a chemical element that decays over time into a more stable form. The rate at which this decay occurs can be used to date substances that contain the isotope

SILICA - a natural substance containing silicon and oxygen that is found in most rocks, sand and clay

At the start of 2022, a submarine volcano in Tonga erupted in an explosion that was hundreds of times more powerful than the atomic bomb dropped on Hiroshima at the end of World War 2. This was the largest volcanic eruption recorded, so far, in the 21st century and it caused devastation throughout the Tongan archipelago and triggered a tsunami that surged across the Pacific Ocean. Eruptions like this have the potential to cause widespread disruption and even pose a threat to human life. Being able to predict when and where these explosive eruptions are likely

to occur next could help nearby populations prepare for the worst.

Volcanic eruptions can vary dramatically in power, duration and frequency. The gentlest eruptions occur with minimal force and involve steady outpourings of lava that move slowly enough that they pose little threat to humans. In certain parts of the world, like Hawaii, these eruptions occur continuously and have even become popular tourist attractions. On the other hand, the most powerful eruptions can be deadly and

unpredictable. These larger eruptions explode with immense power and can trigger tsunamis or pyroclastic flows, making them a much more potent threat to human life.

The geological processes that lead to these large eruptions are complex and can be hard to study, which makes the eruptions hard to predict. Dr Michael Eddy from Purdue University in Indiana is attempting to understand these processes by studying ancient, fossilised volcanoes.

WHAT CAUSES THE MOST EXPLOSIVE ERUPTIONS?

Volcanic eruptions occur when molten rock, or magma, is forced to the surface. The most powerful and explosive eruptions are often caused by rhyolite magmas which have a high silica content. The high levels of silica make rhyolite magma extremely viscous. Substances with a high viscosity, like honey, flow very slowly, while substances with a low viscosity, like water, flow easily. "This property matters," Michael says, "because high viscosity magmas trap gas bubbles as they begin to form, essentially creating a pressure bomb." As the magma rises to the surface, these bubbles of gas merge and eventually burst, which causes an eruption. As high-silica rhyolite magmas are highly viscous and contain lots of dissolved gas, they are, as Michael puts it, "prime culprits for explosive volcanic eruptions".



DR MICHAEL EDDY

Department of Earth, Atmospheric and Planetary Sciences, Purdue University, USA



FIELDS OF RESEARCH

Geology, Geochronology



RESEARCH PROJECT

Studying fossilised magma chambers to uncover the processes behind the planet's most explosive volcanic eruptions



FUNDER

US National Science Foundation (NSF)

magma chambers dominated by liquid rock pose the greatest threat as they are the most likely to cause explosive rhyolite eruptions. Michael and his team are currently working in the Stillwater Range, in Nevada in the US, to determine whether high-silica magma is formed by the same process there.

If Michael's findings are confirmed, geologists may be able to make more accurate predictions about which volcanoes are going to erupt and how dangerous those eruptions might be. If a dangerous eruption is thought to be possible, then special instrumentation can be brought in to monitor the volcano. If these instruments indicate an imminent eruption, local populations can be evacuated before the eruption begins, emergency supplies could be sent to the area and backup communication systems could be set up. After the eruption in January 2022, communications between Tonga and the rest of the world were all but severed and it took days for humanitarian aid to reach the island nation. Having a warning system might have made all the difference. We will never be able to stop volcanic eruptions, but with more accurate predictions, we can be better prepared to deal with their consequences.

Unfortunately, the process that forms rhyolite magmas is still poorly understood. Rhyolite magma is normally formed in chambers in the uppermost part of the Earth's crust. In these chambers, the high-silica magma separates from magma that contains a high density of crystals. The process by which this separation occurs remains unknown and is the subject of Michael's research.

Currently, there are two models that could explain the separation. The simplest explanation is that the crystals sink to the bottom of the chamber and leave the high-silica magma closer to the surface. The other model involves a process known as compaction, in which the crystal-bearing magma is compressed under pressure. As compaction occurs, the high-silica magma is expelled upwards like water being squeezed out of a sponge.

WHY IS IT IMPORTANT TO UNDERSTAND THIS PROCESS?

These two models make two very different predictions about the characteristics of a magma chamber in the build-up to an eruption. Crystals can only sink if the magma chamber is dominated by liquid rock. On the other hand, compaction can only occur if the magma chamber is dominated by crystals. "Geophysicists can use seismic waves to determine whether the magma underneath a modern volcano is crystal-rich or liquid-rich," explains Michael. "Therefore, determining which of these processes leads to the production and eruption of high-silica rhyolite will help them decide which volcanoes pose the greatest hazard."

HOW DOES MICHAEL STUDY THIS PROBLEM?

In certain areas, the movement of rocks over long periods of time have caused ancient volcanoes to tilt, exposing fossilised magma chambers to the surface. "These areas allow us to look at

fossilised magma reservoirs to determine whether crystal settling or compaction occurred," says Michael. He and his team then attempt to match the fossilised chamber with rhyolite eruption deposits on the surface to learn more about how conditions in the magma chamber might have affected the eruption.

Michael specialises in determining the age of rocks, and these skills come in handy when his team is trying to match a fossilised chamber with specific rhyolite deposits. "Showing that an eruption occurred at the same time that a fossil magma reservoir contained liquid is a key part of reconstructing ancient magmatic systems," explains Michael. He can determine the age of rock samples in a laboratory using a process called uranium-lead dating. As we know how long it takes for uranium to decay into lead, Michael can determine the age of a rock sample by observing the amount of uranium and lead present in it.

Michael also spends a lot of time outdoors conducting fieldwork. This involves mapping the different rock types within a field area and collecting samples for analysis. "This is fairly simple," he explains. "It involves breaking up rocks with a sledgehammer!" This mix of field and lab work poses a challenge to geologists like Michael as they need to be skilled in a range of different procedures and techniques. Because of this, Michael's team is made up of scientists who have a range of specialties from studying volcanic deposits to operating special instrumentation that analyses the chemical composition of minerals.

WHAT HAS MICHAEL'S RESEARCH TAUGHT US?

Preliminary findings from this project, along with other areas of Michael's research, suggest that the high-silica rhyolite magma is formed when the crystals sink to the bottom of a magma chamber. This implies that

ABOUT GEOLOGY

Geology is the study of the physical structures and substances that make up the Earth, as well as the processes which have shaped these. It is a broad field that incorporates elements of practically all other scientific fields including physics, biology, chemistry and mathematics. As it encapsulates such a range of topics, geology is often sectioned into smaller, more specified disciplines. These include mineralogy (studying crystal structure), sedimentology (sediments, such as sand and clay), palaeontology (fossils) and volcanology (volcanoes), to name but a few.

Michael specialises in a field known as geochronology, which is the science of dating Earth materials, such as rocks, minerals and sediments, as well as geological events. Geochronologists determine the age of their samples by studying radioactive isotopes

present within them. By observing the ratios of different isotopes, which decay at varying rates, they can make accurate predictions about the age of a sample. Geochronology plays a vital role in many aspects of geology and helps geologists understand the processes that shaped the Earth as we know it.

WHAT DOES A DAY IN THE LIFE OF A GEOLOGIST LOOK LIKE?

Because geology incorporates such a range of disciplines, the daily work of a geologist is likely to vary depending on what they specialise in and where they are in their career. Some geologists will spend a lot of time in the field, making observations, mapping field areas and collecting samples of rocks and minerals. On the other hand, some geologists will specialise in lab work and make use of cutting-edge research tools to analyse samples. Some geologists, like Michael,

get the opportunity to work both in the field and in a laboratory. Michael says, "This approach suits my skills and interests very well and it is what drew me to the field initially."

WHAT RESEARCH OPPORTUNITIES WILL BE OPEN TO FUTURE GEOLOGISTS?

Because of geology's scope, there will be a range of opportunities for budding geologists. "Much of the technology that is used within our society requires elements that must be mined," says Michael. "Learning how to better find and safely exploit deposits of these elements will be an important opportunity for the next generation of geologists." Geologists will also continue to assess the risks posed by seismic and volcanic activity. More recently, geologists have begun investigating how the world will react to climate change.

EXPLORE CAREERS IN GEOLOGY

- The department of Earth, Atmospheric and Planetary Sciences at Purdue (www.eaps.purdue.edu/outreach/index.html) offers a variety of public outreach programmes within the state of Indiana.
- The department also communicates the most recent research results from its faculty through Twitter (@PurdueEAPS) which can be a great way to keep up-to-date with the latest geological research.
 - The British Geological Society (www.bgs.ac.uk/geology-projects/citizen-science) has a number of citizen science projects that you can take part in to get involved in some real geology.
 - Become a student member of The Geological Society (www.geolsoc.org.uk/StudentMembership) for free access to resources and events that can help prepare you for a career in geology.
 - According to Salary.com, the average salary for a geologist in the US is around \$64,000. (www.salary.com/research/salary/listing/geologist-salary)

PATHWAY FROM SCHOOL TO GEOLOGY

- Geologists must be proficient in mathematics, chemistry and physics, in addition to Earth science. Michael recommends that any budding geologists take as many courses in these areas as possible.
- A career in geology generally follows a bachelor's or master's degree in the subject.
 - Michael also recommends that, whilst studying for your degree, you should contact companies that you are interested in working for. Sometimes, these contacts lead to internships and permanent employment.



HOW DID MICHAEL BECOME A GEOLOGIST?



WHAT WERE YOUR INTERESTS WHEN YOU WERE GROWING UP?

I've always been interested in history, both human history and the history of the Earth. In fact, I consider myself an Earth historian because my research helps tell the story of Earth's past. My fascination with the past was present even when I was a child, and from an early age, I collected fossils near my parent's home in North Carolina.

WHO OR WHAT INSPIRED YOU TO BECOME A SCIENTIST?

I was inspired to become a scientist by the educators I encountered in secondary school and at university. My science teachers seemed to understand the world in a way that was very appealing to me, and if they didn't already understand something, they had a method for trying to figure it out!

WHAT ATTRIBUTES HAVE MADE YOU SUCCESSFUL AS A SCIENTIST?

Technical skills in mathematics, physics or chemistry seem to always be highlighted when discussing the success of scientists. However, I think that an intense curiosity about the world and how it works is much more important to a scientist's success.

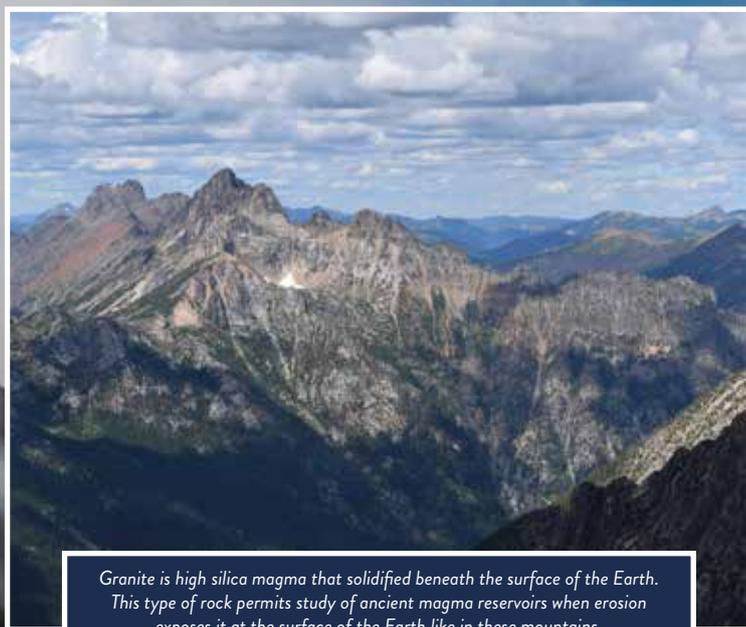
WHAT ARE YOUR PROUDEST CAREER ACHIEVEMENTS SO FAR, AND WHAT ARE YOUR AIMS FOR THE FUTURE?

I'm most proud of my contributions to scientific teams that have constrained things like the rates of volcanic eruptions and how the Earth's climate has changed in the past. Working in teams is one of the most rewarding parts of scientific research. I'm currently building my own research group at Purdue University and my ambition is to put together a team that has fun working on all sorts of geological research problems.

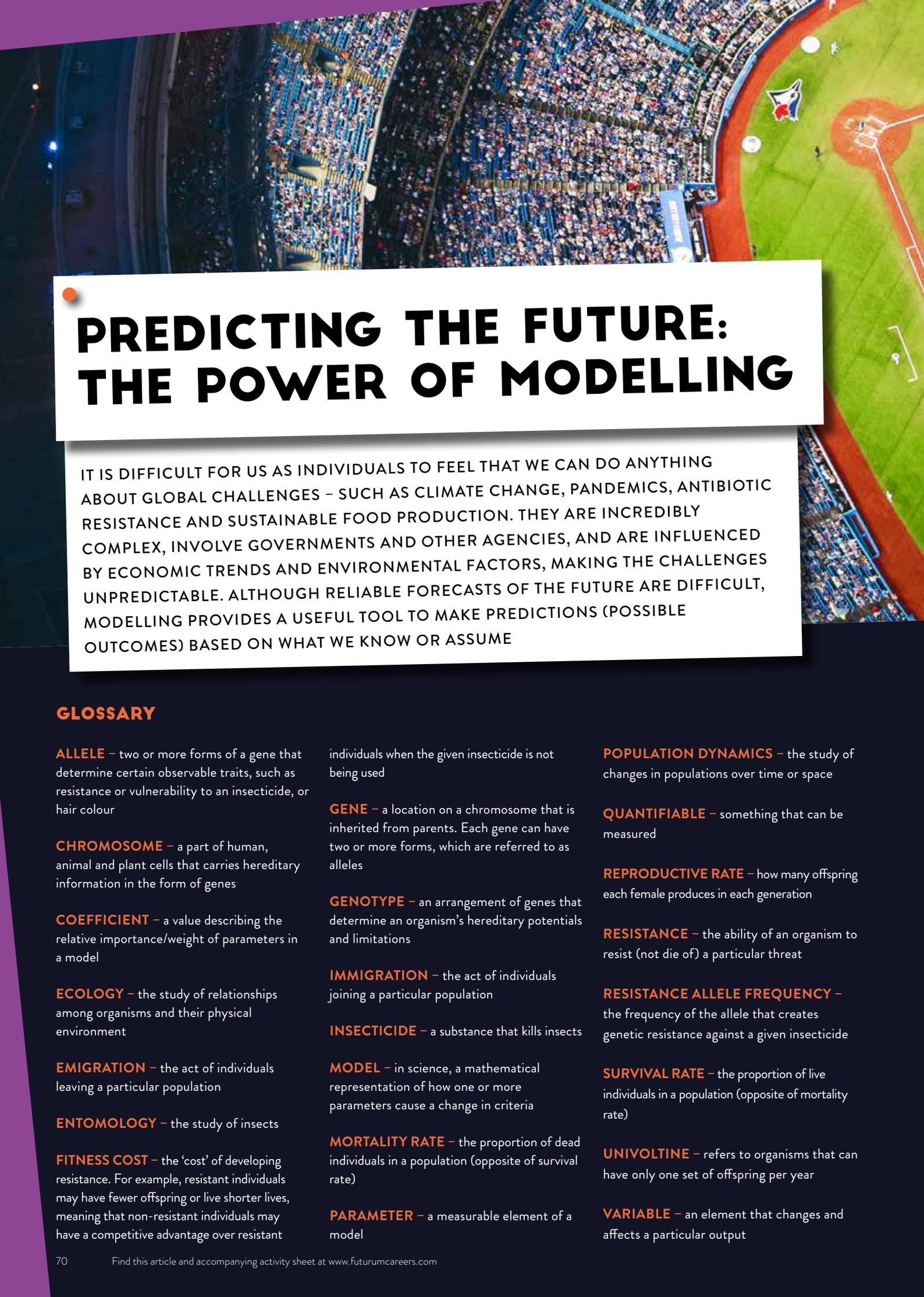


MICHAEL'S TOP TIP

Be curious about the Earth and its history. Ask questions about the Earth and try to find the answers!



Granite is high silica magma that solidified beneath the surface of the Earth. This type of rock permits study of ancient magma reservoirs when erosion exposes it at the surface of the Earth like in these mountains.



PREDICTING THE FUTURE: THE POWER OF MODELLING

IT IS DIFFICULT FOR US AS INDIVIDUALS TO FEEL THAT WE CAN DO ANYTHING ABOUT GLOBAL CHALLENGES – SUCH AS CLIMATE CHANGE, PANDEMICS, ANTIBIOTIC RESISTANCE AND SUSTAINABLE FOOD PRODUCTION. THEY ARE INCREDIBLY COMPLEX, INVOLVE GOVERNMENTS AND OTHER AGENCIES, AND ARE INFLUENCED BY ECONOMIC TRENDS AND ENVIRONMENTAL FACTORS, MAKING THE CHALLENGES UNPREDICTABLE. ALTHOUGH RELIABLE FORECASTS OF THE FUTURE ARE DIFFICULT, MODELLING PROVIDES A USEFUL TOOL TO MAKE PREDICTIONS (POSSIBLE OUTCOMES) BASED ON WHAT WE KNOW OR ASSUME

GLOSSARY

ALLELE – two or more forms of a gene that determine certain observable traits, such as resistance or vulnerability to an insecticide, or hair colour

CHROMOSOME – a part of human, animal and plant cells that carries hereditary information in the form of genes

COEFFICIENT – a value describing the relative importance/weight of parameters in a model

ECOLOGY – the study of relationships among organisms and their physical environment

EMIGRATION – the act of individuals leaving a particular population

ENTOMOLOGY – the study of insects

FITNESS COST – the ‘cost’ of developing resistance. For example, resistant individuals may have fewer offspring or live shorter lives, meaning that non-resistant individuals may have a competitive advantage over resistant

individuals when the given insecticide is not being used

GENE – a location on a chromosome that is inherited from parents. Each gene can have two or more forms, which are referred to as alleles

GENOTYPE – an arrangement of genes that determine an organism’s hereditary potentials and limitations

IMMIGRATION – the act of individuals joining a particular population

INSECTICIDE – a substance that kills insects

MODEL – in science, a mathematical representation of how one or more parameters cause a change in criteria

MORTALITY RATE – the proportion of dead individuals in a population (opposite of survival rate)

PARAMETER – a measurable element of a model

POPULATION DYNAMICS – the study of changes in populations over time or space

QUANTIFIABLE – something that can be measured

REPRODUCTIVE RATE – how many offspring each female produces in each generation

RESISTANCE – the ability of an organism to resist (not die of) a particular threat

RESISTANCE ALLELE FREQUENCY – the frequency of the allele that creates genetic resistance against a given insecticide

SURVIVAL RATE – the proportion of live individuals in a population (opposite of mortality rate)

UNIVOLTINE – refers to organisms that can have only one set of offspring per year

VARIABLE – an element that changes and affects a particular output



Dr Christian Nansen is a professor in the Department of Entomology and Nematology at the University of California, Davis. His teaching, mentoring and research focus on capacity building and innovative solutions within the areas of sustainable food production and pest management. In previous research, Christian worked with drones, robotics, machine vision, phone apps and other technologies. Recently, he developed a freely available model to study insecticide resistance evolution and predict outcomes based on readily available information.

Consider baseball, or any other competitive sport, and imagine predicting a team winning lots of matches and possibly a championship at the end of the season. That is a very complex challenge, which involves considering the performance of all the different team players, the defensive and offensive strategies during a long game (nine innings) and the qualities of other competing teams.

You may think that no one could predict who will win. “True, no one can make a 100% reliable prediction, but it turns out that the game of baseball can be ‘broken down’ into a complex sequence or network of individual events, and each of them can be described mathematically,” explains Christian.

“There is a very popular movie (based on true events), *Moneyball*, describing how a general baseball team manager hired a modelling genius, who developed a mathematical model and was able to predict which players to pick for the team and how they should be playing for the Oakland Athletics to maximise their likelihood of winning matches,” he says. “I strongly recommend you watch this movie and, while watching it, think about how and why it is much more than a movie about baseball.”

In this article, a freely available model about insecticide resistance evolution is used as a case study. But, just like *Moneyball* is a movie about much more than ‘just’ how to win baseball matches, the model describing

insecticide resistance evolution is used to discuss something of much broader relevance. The goal is to demonstrate the purpose and importance of modelling in the classroom. As a basic framework, modelling can be taught to empower and inspire future generations of scientists, teachers and decision-makers.

MODELLING IN DAILY LIFE

Although we may not realise it, we are making model predictions every time we make a decision and/or take an action. “For instance, when we go cycling, we choose to cycle on the road,” says Christian. “Our experience tells us that it is better to ride on a road rather than try to cycle through a house.”

Our experiences also give us a set of ‘rules’ that we follow so that we act appropriately in different situations. Cycling on the streets in the UK and the US has one major difference, which becomes evident very quickly. In the UK, traffic is on the left side, while it is on the right side in the US. So, different models are used to maximise our safety while cycling in different countries, and mathematical models work in the same way.

“Models are adapted to local conditions and that leads to specific outcomes. The more information we put into the model, the more likely it is that the model represents our current body of knowledge about the particular challenge,” Christian explains. “If a model is detailed, that is, it includes many parameters, it is also more likely to produce meaningful and useful predictions.”

When making predictions about complex issues, it is important to remember that models are never 100% accurate – they are associated with some degree of ‘error’ (inaccuracy). “Take your health as an example,” says Christian. “We know from experience and education that exercise is good for our health, and smoking and alcohol are bad for our health, so we can ‘predict’ that adopting a habit of smoking, for instance, will affect our health negatively.”

From decades of scientific study, we know that smoking is likely to have a more significant



DR CHRISTIAN NANSEN

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FIELD OF RESEARCH

Insect Ecology and Management



RESEARCH PROJECT

Developing an interactive teaching tool that describes resistance evolution and basic economics of insecticide-based pest management

impact on our health than some other unhealthy habits, such as drinking coffee or sugary soft drinks. But it is not 100% certain that smokers get ill or die younger than non-smokers, because many variables determine our health.

For example, coffee or sugary soft drinks may be particularly harmful to certain people with other health conditions. “But we can make general recommendations based on what we know and based on what is most likely to happen,” says Christian. “And then we can develop specific models for children, men, women or other specific demographic groups – this is precisely how fitness watches model our health and give us suggestions of how to stay healthy.”

MODELLING OF INSECTICIDE RESISTANCE EVOLUTION

“The science behind this model involves a general understanding of genetics, evolutionary processes, insect population dynamics and economics of crop production and pest management,” explains Christian. This means that a wide range of different variables, biological and economical, are known to interact in complex ways and influence the likelihood of a particular insect pest population developing resistance to an insecticide over generations of insect pests.

“THE SAME CHALLENGE IS EVOLVING IN AGRICULTURE; INSECT PESTS THAT CAUSE DAMAGE TO LIVESTOCK OR CROP PRODUCTION SYSTEMS EVOLVE RESISTANCE TO THE INSECTICIDES USED TO CONTROL THEM.”



“Many people understand the concerns and risks associated with resistance to antibiotics; certain medications are no longer capable of protecting us against bacterial infections because the bacteria have developed resistance,” says Christian. “The same challenge is evolving in agriculture; insect pests that cause damage to livestock or crop production systems evolve resistance to the insecticides used to control them.” This gene is assumed to have two alleles, which are two forms of the gene – these forms are ‘R’ (resistant) or ‘S’ (susceptible).

Because almost all insects are diploid (have two complete sets of chromosomes), it means

that for this gene, all insects have one of these three genotypes: SS, SR or RR. Although genotypes can interbreed, they are assumed to have different growth parameters (for instance, how long they live, how many eggs they lay or survival rates of different life stages). Another critically important aspect of predicting resistance evolution is to obtain information about allele frequencies: how rare is the resistance allele?

“When an insecticide is applied to a crop, it acts as a selection pressure on the pest population – it will kill individuals that are susceptible but not the individuals that (based on their unique behaviour or genetic make-up)

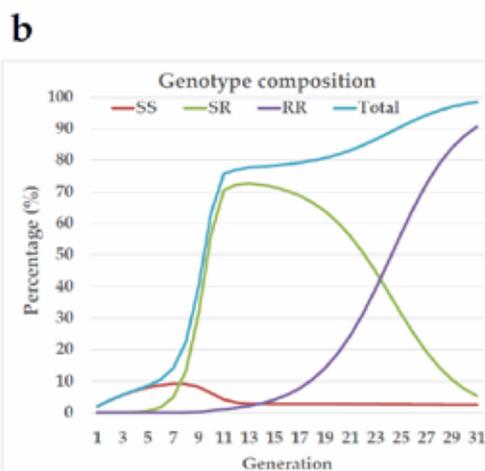
are resistant,” explains Christian. If one in five (20%) of pest individuals is resistant, then, in a few generations, the total population will be completely resistant, because that is a very high level of resistance. In most studied cases, resistance allele frequencies are 1 in 1,000 (0.001 – 99.9% are susceptible), so it takes 10 or more generations before resistance alleles become abundant within insect populations. But it is not only resistance allele frequency that determines how quickly resistance develops.

When you buy disinfectants to clean surfaces in bathrooms or kitchens, you will often see on the label that these products are assumed to kill 99.99% of germs, bacteria or pathogens (whatever term

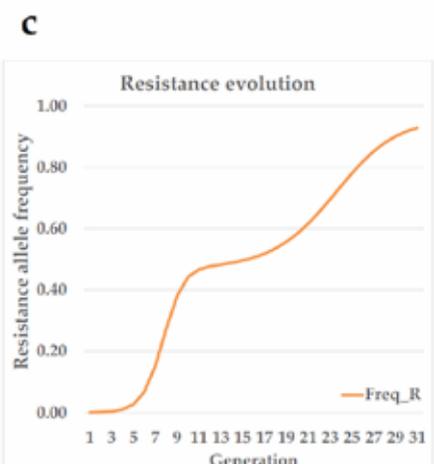
a

Carrying capacity (K)	1000		
R allele frequency	0.001		
	SS	SR	RR
Survival (W) (≤ 1)	0.20	0.70	1.00
Fitness cost (F) (≤ 1)	0.00	0.00	0.00
Reproductive rate (R)	5.00	5.00	5.00
Emigration (0 $\leq e$ <math>< 100</math>)	2.00	2.00	2.00
Immigration (0 $\leq i$ <math>< 100</math>)	2.00	2.00	2.00
EIL	0		
Damage rate (≤ 0)	0.00		
Treatment cost (≤ 0)	0.00		
Yield potential (≤ 0)	0.00		

Table (a) shows genetics (green) and basic economics of pest management (blue)



Graph (b) shows genotype composition



Graph (c) shows resistance allele frequency over 30 discrete and univoltine generations

they use to describe 'the bad guys') so only 1 in 10,000 survives. This sounds excellent, but if there are 1 million bad bacteria on a kitchen surface (which is possible), 100 bacteria ($0.0001 \times 1,000,000$) will survive the cleaning process!

The first time the cleaning agent is used, the bacterial population will be significantly reduced, but it may be able to gradually rebound if the resistant individuals are allowed to thrive and multiply, and if they have a high growth rate. Christian explains that if they do, then there has likely been a shift in the population's genetic composition: before cleaning, the vast majority were SS, while after several generations and selection pressure by the cleaning agent, the bacterial population becomes predominantly highly resistant, RR.

"Therefore, when antibiotics are 1) prescribed too frequently to patients and 2) given excessively to livestock to stimulate growth and protect against infections, antibiotic resistance becomes a problem," says Christian. "And similarly, if bacterial cleaning products are used widely and excessively, then they may lose their effect over time for the same reason."

A REAL-WORLD CHALLENGE

There is a fundamental dilemma in health care and pest management in agriculture: we want to use the most effective medicine, cleaning agents and pesticides. But the most effective products should only be used as a last resort,

because if used too widely and frequently, human diseases, surface pathogens or crop pests may develop resistance.

Because of this basic dilemma, modelling can be used to optimise the use of an insecticide to achieve the highest level of pest control over time and, at the same time, minimise the risk of pest populations developing resistance. That is the basic biological challenge, and then we can add an economical dimension to optimise the economic sustainability of pest management.

"By now, I hope you can appreciate that, although modelling effects of climate change and minimising risks of insecticide resistance evolution are different from modelling outcomes of baseball games – there are striking similarities!" says Christian. "We have great interest in predicting outcomes, these challenges are highly complex, and each of these challenges can be broken down into a series of parameters in a model."

Christian explains that in the model of insecticide resistance evolution, decades of research have provided ample insight into critical variables; these include reproductive rate, immigration rate, emigration rate, resistant allele frequency and fitness cost. These and other variables have been included as parameters in the model, and they can be examined in different combinations. The model is freely available as an interactive Excel spreadsheet. "Through hands-on

experience with this and similar interactive teaching tools, students will acquire fundamental knowledge about basic population models and gain experience with quantitative data interpretation," Christian explains. The model can be downloaded freely from Christian's website (chnansen.wixsite.com/nansen2/teachingtool), which also offers a tutorial video on using the model.

MODELLING AND TEACHING

Christian believes that teachers and students will benefit from the interactive teaching tool. "Teachers can use the interactive tool to demonstrate how models can help visualise complex interactions," says Christian. "Students can use the tool to test different scenarios and observe the effects of changing parameters."

Rather than a learning process focused on memorisation, the teaching tool encourages students to think about why various scenarios lead to different outcomes, and how these outcomes can be influenced. Many young people express deep anxieties about the future of the world and, often, with good reason.

Christian believes that models can help address these worries. "Models help show that the future is somewhat 'predictable' – which means that certain outcomes can be avoided," says Christian. "This shows students that, provided we adjust the underlying variables, we have the power to change the future."

"THROUGH HANDS-ON EXPERIENCE WITH THIS AND SIMILAR INTERACTIVE TEACHING TOOLS, STUDENTS WILL ACQUIRE FUNDAMENTAL KNOWLEDGE ABOUT BASIC POPULATION MODELS AND GAIN EXPERIENCE WITH QUANTITATIVE DATA INTERPRETATION."

CAN MACHINE LEARNING COPE WITH THE ERRATIC AND UNCERTAIN NATURE OF THE REAL WORLD?

UNTIL RECENTLY, SELF-DRIVING CARS AND ROBOTIC HOUSEKEEPERS WERE THE STUFF OF SCI-FI MOVIES. HOWEVER, IN THE LAST DECADE, THE CAPABILITIES OF ARTIFICIAL INTELLIGENCE HAVE BEEN EXPANDING AT BREAK-NECK SPEED. AT THE **UNIVERSITY OF SOUTHERN CALIFORNIA, USA, DR HAIPENG LUO** HAS BEEN CONDUCTING INNOVATIVE NEW RESEARCH IN THE FIELD OF MACHINE LEARNING TO BRING THESE EXCITING TECHNOLOGIES WITHIN REACH

TALK LIKE A MACHINE LEARNING SCIENTIST

ALGORITHM – a sequence of well-defined rules that allows computers to make calculations and solve problems

MACHINE LEARNING – a type of artificial intelligence in which computers learn from past data in order to predict outcomes more accurately

NON-STATIONARITY – the quality of being subject to unexpected changes. A non-stationary environment has rules that may change over time

REINFORCEMENT LEARNING (RL) – an area of machine learning that investigates how algorithms can learn about their environments and make good decisions through reward signals

REWARD SIGNAL – feedback from an environment that informs an algorithm whether an action it has taken was good or bad

Do you ever get the feeling that you are being watched? It can feel slightly disconcerting when an advert for a band you have just been listening to or a TV show you have just been watching pops up on your social media feed. Although

you do not need to worry that a government spy is observing you through your webcam, this targeted advertising is no coincidence.

Companies such as Google, Netflix and Facebook use a type of artificial intelligence known as machine learning to help them better understand their users. Each time you search for something on the internet, machine learning algorithms track your activity to learn about your interests. They then use this information to tailor your adverts and film recommendations based on what they think you will want to buy or see.

Reinforcement learning (RL) is a branch of machine learning in which an algorithm learns about its environment through a reward system that provides feedback on its actions. Each time the algorithm performs an action, the environment will change state and issue a reward signal to the algorithm. This signal will be positive when the algorithm makes a good decision and negative when it makes a bad one. At first, the algorithm may make lots of mistakes. However, over time, the algorithm will learn how its actions affect the environment and which of these actions are desirable. Thanks to the positive and negative reinforcement provided by the reward signals, the algorithm will learn to make fewer mistakes and so will become better adapted to its environment.

While RL algorithms are currently used in robotics and telecommunications, they have certain characteristics that limit their ability to function in wider real-world settings. At

the University of Southern California, Dr Haipeng Luo has developed a new approach to reinforcement learning that may solve these problems.

LIMITATIONS OF REINFORCEMENT LEARNING

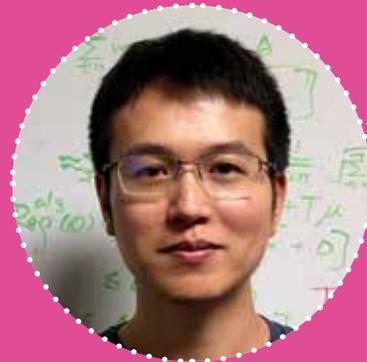
Traditional RL algorithms only work in stationary environments. For example, RL has been used to train computers to play Atari arcade games, such as Space Invaders. Since these games are designed according to fixed rules, the environment in which the RL algorithms work is stationary.

In stationary environments, the consequences of the algorithm's actions will always follow the same rules. Similarly, the reward signals that the algorithm receives from the environment will remain consistent. In other words, "if the same action is taken in the same state, the distribution over the outcome or 'next-state' will be the same, and the reward signal will be the same" says Haipeng.

"This is a huge limitation," he continues, "because in practice, environments are constantly changing." For example, if there are multiple RL algorithms in an environment, their behaviour is likely to change as they learn and improve. Such an environment would be highly non-stationary, and a traditional RL algorithm would struggle to perform effectively.

THE COMPLEXITY OF NON-STATIONARY ENVIRONMENTS

Most real-world environments are non-stationary, with conditions that are constantly



DR HAIPENG LUO

University of Southern California, USA



FIELD OF RESEARCH

Machine Learning



RESEARCH PROJECT

Developing new algorithms to help machine learning systems perform in real-world environments



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changing, and so it is hard for traditional RL algorithms to function. It is difficult to predict how non-stationary an environment is going to be before the algorithm starts interacting with it. Even once the algorithm has started to explore its environment, the feedback which it receives is limited. "The agent only receives the reward for an action that it has taken," says Haipeng. "Therefore, it cannot figure out what would have happened if it took a different action."

This means these RL algorithms cannot be used for many applications. For example, self-driving cars must navigate the particularly non-stationary environments of busy roads. "On the road, conditions can change quickly and unexpectedly, and the behaviour of other cars and pedestrians can be unpredictable and random." For such complex environments, a new approach to designing RL algorithms is needed. This is the focus of Haipeng's research.

HOW HAS HAIPENG TACKLED THIS CHALLENGE?

There are two key ideas in Haipeng's new approach, the first of which involves using a pre-existing algorithm to detect the non-stationarity of the environment. This pre-existing algorithm is known as a base algorithm. Haipeng selects a base algorithm that performs optimally in a stationary environment. If the base algorithm does not perform as well as expected in the environment under investigation, then that environment must be non-stationary.

Haipeng's second idea was to use multiple copies of the base algorithm and run them for

different lengths of time. The algorithms that run for short durations can detect large changes in the environment, while the longer-running algorithms detect smaller changes. Once an algorithm has finished, Haipeng conducts statistical tests to determine how non-stationary the environment is.

WHAT ARE THE BENEFITS OF HAIPENG'S APPROACH?

One of the main benefits of Haipeng's new approach is that it is applicable to a wide range of situations, as long as a base algorithm exists. Through his approach, any RL algorithm that works in a stationary environment can be transformed so that it works in a non-stationary environment. Another benefit is that this transformation is easy to implement. The base algorithm can remain unchanged and would simply need to be 'wrapped' in Haipeng's new algorithm to greatly improve its performance.

Haipeng has also proven that his method produces the best statistically possible performance for any given environment. This is particularly impressive when one considers that this is achieved without even knowing how non-stationary the environment is.

HOW GROUND-BREAKING IS THIS RESEARCH?

Haipeng's research has had a significant impact in the field of machine learning. In 2021, Haipeng and his student, Chen-Yu Wei, won the best paper award at the Annual Conference on Learning Theory, the world's most prestigious

conference on machine learning theory. "This is a huge honour for us," says Haipeng.

Being selected as the best paper from hundreds of other submissions is a sign of how widely regarded Haipeng's research is. "While I have won similar awards previously, this award is especially meaningful for me as a young assistant professor, because the work was done by my student and myself only," he says.

NEXT STEPS

Haipeng's current work considers the perspective of a single RL algorithm within a non-stationary environment. One key next step is to consider how several RL algorithms would work simultaneously within a non-stationary environment. There are many more questions to consider in a multi-agent system. For example, how would each algorithm's learning process be affected by the other algorithms? And how would other causes of non-stationarity in the environment affect this? While there is still a lot of work to be done, Haipeng and Chen-Yu's solution to the complex problem of non-stationarity is a major step forward.

ABOUT MACHINE LEARNING

Machine learning is a subfield of artificial intelligence. Researchers in this field, sometimes known as machine learners, develop algorithms that can figure out how to improve their own performance. There are many applications for machine learning algorithms, from social media and online streaming platforms to agriculture and medicine.

Due to its huge potential, research into machine learning techniques has surged in recent years. As a result, the global machine learning market is expected to be worth over \$30 billion a year by 2024. This makes it an exciting time to be a machine learner.

Machine learners use a mix of mathematics and computer science to develop and test their algorithms. While the maths can be complicated and coding is a skill that requires a lot of hard work to master, the rewards are worth it. Machine learners address all kinds of real-world problems, and their algorithms may help society

solve some of its biggest challenges.

WHERE IS MACHINE LEARNING FOUND IN OUR DAY-TO-DAY LIVES?

Machine learning is already fully integrated in our daily lives. “Examples include automatic translations, fraud and spam detectors, and face and voice recognition software,” says Haipeng. Streaming services such as Netflix and Spotify use machine learning to recommend new movies, TV programmes and songs they think you will want to watch or listen to, based on your previous viewings. In the field of medicine, machine learning is used to help doctors make correct diagnoses and prescribe appropriate medicines to their patients.

HOW WILL MACHINE LEARNING ADVANCE IN THE FUTURE?

Currently, machine learning relies on training gigantic statistical models with a huge amount of data. “To make machine learning more general and versatile, I think being able to learn from a

small dataset, either via transferring knowledge from other similar tasks or via some kind of logistical reasoning, would be an important next step,” says Haipeng.

A key challenge when developing machine learning systems is the consideration of societal and ethical impacts. “The next generation of computer scientists will have to ensure fairness, accountability, transparency and ethics (FATE) in artificial intelligence systems,” says Haipeng.

WHAT ARE THE REWARDS OF WORKING AS A COMPUTER SCIENTIST?

Haipeng enjoys being able to do maths that has applications in the real world. “I enjoy developing algorithms, deriving theory for them, and, finally, implementing them as a computer program to solve problems,” he says. “I like that machine learning combines two of my favourite subjects, math and computer science, to solve real-life problems in an unprecedented way.”

EXPLORE CAREERS IN MACHINE LEARNING

- There is currently a huge demand for machine learners and there are a variety of career paths to follow. For example, you could be a software engineer at a tech start-up, an analyst in the finance industry, a research scientist in an industrial lab or a professor at a university.
- Haipeng recommends searching online to find useful and interesting resources about machine learning, from forums and blog posts to courses and YouTube videos. “Learning to find the materials you need online is one of the most useful skills in the age of the internet!”
- The School of Engineering at the University of Southern California provides a wealth of resources for students and teachers, including many to help you learn programming languages and how to code: viterbik12.usc.edu/resources
- The School of Engineering also offers high school students the chance to participate in an 8-week research project through the SHINE programme: viterbik12.usc.edu/shine
- The following article discusses how to become a machine learning engineer, what skills you will need to develop, and the work you can expect to do: www.csuglobal.edu/blog/how-become-machine-learning-engineer

PATHWAY FROM SCHOOL TO MACHINE LEARNING

- Haipeng recommends studying computer science courses to learn about programming, data structures and algorithms. He also recommends studying maths subjects such as algebra, calculus, probability and statistics.
- Most universities offer degrees in computer science, and some may offer specialised degrees in machine learning.

HOW DID HAIPENG BECOME A MACHINE LEARNING SCIENTIST?

WHAT WERE YOUR INTERESTS WHEN YOU WERE YOUNGER?

When I was young, my interest was mainly in mathematics. Growing up, I had no access to computers, however this changed when I started studying at Peking University in Beijing, China. I was able to take all kinds of computer science courses and learnt to program computers, and I quickly fell in love with this subject.

WHAT INSPIRED YOU TO BECOME A COMPUTER SCIENTIST?

During my first year of undergraduate study, I heard about a programming competition called the International Collegiate Programming Contest. I was also made aware of some legendary Chinese contestants. I thought it was such a fascinating event, so I started training myself to take part in it. Eventually, I became part of Peking University's team and started competing in the contest. Although I never made it to the top level, I still think this is the most important thing that inspired me to continue studying in this field and to become a computer scientist.

DURING YOUR PHD STUDIES, YOU CONDUCTED RESEARCH INTERNSHIPS WITH AT&T, YAHOO AND MICROSOFT. WHAT DID YOU GAIN FROM THESE EXPERIENCES?

These experiences greatly expanded my research capabilities, especially from a practical side. For example, I learnt what it is like to work in an industrial lab. This helped me understand what kind of practical problems scientists in these labs work on and how to test the performance of proposed algorithms on a real system.

WHAT PERSONAL QUALITIES HAVE MADE YOU SUCCESSFUL AS A SCIENTIST?

The most important one is probably always being curious. I always ask myself why things work the way they do, how to improve them and whether they can be generalised to other problems or be united with other approaches. I find that these are often the most important questions to ask as a scientist.

WHAT DO YOU ENJOY DOING OUTSIDE OF WORK?

I have many hobbies, including playing ping pong, badminton and video games. I also enjoy playing the guitar and the piano, as well as hiking, travelling and watching movies. Unfortunately, I rarely have enough time to enjoy all these things regularly!

HAIPENG'S TOP TIPS

1. Find something you feel passionate about. I think that working on your true passion is the key to success.
2. Be curious and ask questions about how things work.
3. Explore all your options. Even within the field of computer science there are so many different directions you could pursue.

NUMBERS AND NETWORKS: HOW CAN WE USE MATHEMATICS TO ASSESS THE RESILIENCE OF GLOBAL SUPPLY CHAINS?

IN RECENT YEARS, GLOBAL SUPPLY CHAINS HAVE FACED DISRUPTIONS FROM NUMEROUS CAUSES, FROM A SINGLE SHIP BLOCKING THE SUEZ CANAL TO THE INTERNATIONAL IMPACTS OF THE COVID-19 PANDEMIC. WHEN PRODUCTION HALTS OR TRADE ROUTES ARE BLOCKED, WHETHER ON A LOCAL OR GLOBAL SCALE, VITAL SUPPLY CHAIN NETWORKS ARE IN DANGER OF LEAVING CRITICAL NEEDS UNMET. AT BRIGHAM YOUNG UNIVERSITY IN THE US, DR ZACH BOYD IS USING HIS MATHEMATICAL SKILLS TO DETERMINE HOW BEST TO PROTECT OUR SUPPLY CHAINS

TALK LIKE A MATHEMATICIAN

CASCADING FAILURE – when a disruption in one link or node of a network spreads throughout the whole network

EDGES – the interactions between nodes in a network e.g., synapses connecting neurons in the brain or customer-supplier relationships between companies in a supply chain

NETWORK – a collection of entities

(nodes) that interact with each other (edges)

NODES – the entities that interact with each other in a network, e.g., neurons in the brain or companies in a supply chain

SUPPLY CHAIN – a network through which a company acquires the goods and materials it needs to make its products

Whether you are aware of it or not, your life is infused with networks. The 86 billion neurons in your brain are linked by synapses to form a vast network that allows you to think, make decisions and perceive the world around you. The relationships you share with your friends and family form a complex social network that supports you throughout your life.

Though networks can vary dramatically in their size, complexity and function, they all share a similar structure. A network is a collection of entities (known as nodes) that interact with each other. These interactions (known as edges) link the nodes together. For example, if you have an Instagram account, you can connect to other users by following their accounts. In this scenario, the nodes of your Instagram network are the accounts you follow and that follow you, while these acts of following are the edges.

As networks are so pervasive in our lives, it is important we understand the rules they follow and the properties they share. Dr Zach Boyd, a mathematician at Brigham Young University, is studying global supply chain networks so that we know how best to react when these vital networks falter.

WHAT IS A SUPPLY CHAIN NETWORK?

A supply chain network consists of companies (nodes) that trade with each other (edges). Most of the trade interactions are customer-supplier relationships, involving one company buying materials or products from another. Zach uses the example of a pencil manufacturer to explain:

“In order to make pencils, PencilCo needs to buy wood from WoodCo, graphite from GraphiteCo and metal (to hold the eraser) from MetalCo. So, these three suppliers would

be connected to PencilCo. Now, each of these three companies will also have their own suppliers. For example, MetalCo might need to buy metal ore from OreCo and specialised chemicals from ChemCo.”

Supply chain networks can become incredibly complex, containing thousands of companies that are all connected in an intricate web of dependency. For example, ChemCo may need to buy pencils from PencilCo for the staff in its offices to use. Relationships like this cause the supply chain to loop back on itself and increase in complexity.

BUILDING MATHEMATICAL MODELS

Zach and his team analyse huge amounts of data to create mathematical models that help them assess the health of supply chain networks. These data mostly come from compliance reports that companies must submit to be registered on the stock market. In these reports, companies are required to disclose their major suppliers and customers. “Mathematically, these records make it fairly easy to construct a supply chain network,” says Zach. However, it is predominantly large companies that submit compliance reports, meaning that many small, but potentially integral, companies are not included in the models.

Zach and his team are working hard to make their models more realistic. They use statistical tools to understand how smaller companies may



DR ZACH BOYD

Brigham Young University, USA



FIELD OF RESEARCH

Mathematics



RESEARCH PROJECT

Creating mathematical models of global supply chain networks to protect them from disruptions



FUNDER

US National Science Foundation (NSF)
This work is supported by the NSF, under award number 2137511. The contents are solely the responsibility of the authors and do not necessarily represent the official views of the NSF.

fit into a network and they gather additional data from other sources. For example, as transportation networks play a key role in moving goods and materials from suppliers to customers, Zach hopes to integrate models of global transportation networks into his models of global supply chain networks. “This will be a quantum leap forward in terms of realism,” he says.

ASSESSING SUPPLY CHAIN RESILIENCE

Once Zach and his team have created a model of a supply chain network, they run simulations to assess how resilient the network might be when faced with disruptions. For example, if the ChemCo factory shuts down, how will this impact PencilCo’s production of pencils?

Interpreting these simulations can be difficult. Historically, mathematicians have analysed aspects such as how closely connected all nodes are in a network. “But this is far too simplistic,” says Zach. On the other hand, supply chain practitioners try to calculate the actual flow of goods between each node. “But this is hard to do with networks containing thousands, or even millions, of companies,” he says.

Zach’s team is developing a compromise between these two extremes. “We keep some of the micro-supply chain insight, while simplifying the approach enough that we can make statements about large and diverse supply chains.”

WHY IS IT IMPORTANT TO ASSESS THE HEALTH OF SUPPLY CHAIN NETWORKS?

Supply chain networks are prone to disruptions which can have widespread consequences. “Most daily supply chain disruptions are from very mundane things, like a truck breaking down or a vendor running out of stock,” explains Zach. While these issues are usually trivial, disruptions to one link or node of a supply chain can propagate throughout a network, resulting in a ‘cascading failure’ that impacts the entire network. Zach is investigating these large-scale disruptions.

For example, in March 2021, the cargo ship *Ever Given* became stuck in the Suez Canal in Egypt for six days, blocking one of the world’s busiest trade routes and causing disruption on a global scale. During the COVID-19 pandemic, factories were shut down and national borders were closed, preventing goods from being manufactured and distributed, resulting in supply shortages around the world.

Global supply chains are still recovering from the cascading failures caused by these disruptions. “Governments and companies want to do something,” says Zach. “But it is not very clear what actions will be most helpful and practical, or how to prevent similar issues from happening again. I’m trying to build mathematical tools and models that make it

possible to produce good advice that we can have confidence in.”

LOOKING TO THE FUTURE

Zach’s next step will be to investigate the best recovery strategies for different kinds of supply chain disruption, while also continuing to refine his models to make them even more realistic. “I am also interested in bringing more researchers from diverse fields together in this discussion,” says Zach. “There is a lot of expertise spread across the world that can contribute to solving these complex problems.”

This multi-disciplinary approach may prove to be crucial. As we move deeper into the climate crisis, many global supply chains are at risk of disruption from extreme weather events, crop failures and new disease outbreaks. Researchers from all disciplines will have to work together to find solutions to these problems, and mathematicians like Zach will have a big role to play.

ABOUT MATHEMATICS

Mathematics is the incredibly broad field that covers numbers, shapes and formulas. There are many branches of maths, including algebra, geometry, calculus and statistics. Pure mathematicians study mathematical concepts in their abstract forms, while applied mathematicians use maths to solve problems in the real world and are, therefore, an essential part of many other disciplines, such as the natural sciences, engineering and finance.

WHAT DOES A DAY IN THE LIFE OF A MATHEMATICIAN LOOK LIKE?

Zach spends his working days doing a variety of different tasks. He teaches classes of university students, works on research problems, writes up his findings and mentors students as they complete their own research projects.

HOW CAN MATHS SOLVE REAL-WORLD CHALLENGES?

“There are so many applications of math!” says Zach. “For pretty much any big problem in the world, there is probably a group of mathematicians out there working to fix it.” Zach is applying his mathematical skills to address a range of challenges beyond supply chain networks. He is working with psychologists and neuroscientists to understand how people recover from bad habits, with genealogists to help people find information about their ancestors, and with artificial intelligence researchers to make smarter algorithms for advertising. “Math really is everywhere!” says Zach. “If you know math, it gives you incredible power to contribute to all kinds of fields.”

HOW CAN MATHS HELP US IN EVERYDAY LIFE?

Having a good understand of maths and numbers can help you in many areas of your life. For example, knowledge of maths can make you better at handling your money and help you avoid scams. “Most of these things are not taught directly in classes,” says Zach. “But having a good quantitative head will make you more confident in many areas of life where it is necessary to judge the size or likelihood of something.”

EXPLORE CAREERS IN MATHEMATICS

- “Mathematicians tend to find themselves in jobs that are perceived as technically challenging, where a little extra ingenuity can generate a lot of value,” says Zach. These include stock market analysis, artificial intelligence, supply chain optimisation and medical engineering, but mathematicians can end up working anywhere!
- The Mathematical Association of America has many resources for high school students who are considering a career in mathematics: www.maa.org/member-communities/students/student-resources/high-school
- The Society for Industrial and Applied Mathematics has resources for schools, information about mathematical careers and lists maths-based internships in industries: www.siam.org/students-education/resources/for-k-12-students
- Prospects lists some of the wide range of careers available for those with a degree in maths: www.prospects.ac.uk/careers-advice/what-can-i-do-with-my-degree/mathematics

PATHWAY FROM SCHOOL TO MATHEMATICS

- Zach recommends taking as many maths classes as you can throughout your education. Linear algebra, statistics and computer programming are particularly useful. “If possible, take a proofs class, as learning to structure your thinking and spot logical gaps will be important in all areas of your life,” says Zach.
- Join the maths club at your school and participate in maths competitions. Teach yourself coding using online tutorials and take part in a Kaggle machine learning competition (www.kaggle.com/competitions). These activities will all hone your skills.
- Most universities offer degrees in mathematics or related fields. The Top University Guide provides information about different maths degrees and what courses cover: www.topuniversities.com/courses/mathematics/guide



HOW DID ZACH BECOME A MATHEMATICIAN?

HAVE YOU ALWAYS BEEN INTERESTED IN MATHEMATICS?

I was interested in math from a young age. I was good at it, so many teachers provided lots of encouragement. But I had very broad interests. I had the hardest time picking a college major as everything interested me. Many of the classes I took didn't end up directly contributing to my career. I don't think that's a problem though, especially when you are young and building a broad foundation for who you are going to be.

WHAT ARE YOUR PROUDEST CAREER ACHIEVEMENTS SO FAR?

Mostly, I'm proud to have been able to carve out a niche for myself where I can do what I love, work with students, grow personally and do work that it is useful to the broader community.

YOUR LAB GROUP IS UNUSUAL AS IT PREDOMINANTLY CONTAINS YOUNG UNDERGRADUATE RESEARCH ASSISTANTS. WHY IS IT IMPORTANT TO GIVE STUDENTS RESEARCH EXPERIENCE EARLY IN THEIR STUDIES?

I'm trying to provide opportunities for people who are just starting out to experience the joy of diving deep into problems and to acquire the self-guided learning skills that they will need in the rest of their lives. I can point them in good directions and help them work through the frustration, and then when they make progress, they know they did something amazing, something beyond anything most of them would ever do in a class. I just love to see them grow and succeed.

ZACH'S TOP TIPS

1. Don't get discouraged by setbacks. Everyone experiences challenges and rejection, so you may as well do what you enjoy!
2. Make sure you live a balanced life. Take time to look after your soul and your relationships, especially with your family. These things are more important than any math you could do.
3. Go for it and have fun!

WHAT DO YOU ENJOY DOING IN YOUR FREE TIME?

I spend a lot of time with my kids – playing, coaching soccer, that kind of thing. I also play a fair amount of racquetball and do yoga.



MEET JASON

Jason Vasquez is an undergraduate student working with Zach on his supply chain network research.

WHAT WERE YOUR INTERESTS WHEN YOU WERE YOUNGER?

I have always been interested in math. Even back in 3rd grade, I was part of my school's math club. I also have a love for history and trivia, I have played the piano for 14 years, and I am captivated by cryptography and code breaking.

WHAT INSPIRED YOU TO STUDY MATHEMATICS?

When I was younger, I loved math. But for some

reason I didn't think that I could study it because I thought it wouldn't lead to a job. Turns out, I was wrong. I took a physics class in high school and thought that might be a good application for my interests. However, when I got to college, I realised that what I loved about physics was the math behind it. I started to look into careers in math and I realised that there are so many options.

WHAT IS YOUR ROLE IN ZACH'S LAB?

I am conducting my own research relating to cascading failures of supply chains and I am currently writing a paper about this work. I have also helped Dr Boyd with a paper about supply chain networks, which I will be a co-author of.

HOW ARE YOU BENEFITTING FROM THE EXPERIENCE OF WORKING IN A RESEARCH LAB AS AN UNDERGRADUATE STUDENT?

I have learned so much since joining the lab. I knew next to nothing about research or what to do when I started, but Dr Boyd has mentored me every step of the way. I feel like I have the experience that I need to grow my breadth of research and to apply for graduate schools when the time comes.

WHAT ARE YOUR HOPES FOR THE FUTURE?

I hope to attend graduate school – I am specifically interested in studying machine learning. I would love to work in industry for a tech company, but I am also considering obtaining a PhD and working in academia in this area.

“THE BIGGEST TAKEAWAY FOR ME IS RECOGNISING THAT YOUNG PEOPLE WANT THE SAME THINGS FROM EDUCATION THAT CHANGEMAKER ADULTS WANT.”

IN GREATER MANCHESTER, UK, OVER THE COURSE OF ONE YEAR, 20 HEADTEACHERS HAVE COME TOGETHER WITH 20 YOUNG PEOPLE TO SHARE BEST PRACTICES AND INITIATE CHANGE IN THEIR SCHOOLS. TWO HEADTEACHERS TALK ABOUT THEIR EXPERIENCES SO FAR WITH ASHOKA AND THE EDGE FOUNDATION'S NEW CAPABILITIES FOR A NEW WORLD PROGRAMME

“As schools return after a tumultuous two years, they have an imperative to seek out approaches that prepare young people to thrive in an increasingly complex world and address equity in new ways,” says Shaun McInerney, Programme Lead for New Capabilities for a New World. “The New Capabilities for a New World programme will support secondary headteachers to explore their own leadership and review whole school strategy through the lenses of changemaking and best practice in real world learning. It is exciting to be able to share Ashoka and Edge’s pioneering work in these areas to inform thinking at this formative time of change and renewal.”

In 2015, Matthew Moss High School in Rochdale, Greater Manchester, was one of 15 schools selected by Ashoka as a changemaker school. The school encourages learner-led classrooms, where students co-construct their learning experiences, and supports social and emotional development alongside academic studies. On 29th April 2016, as part of the New Capabilities for a New World programme, headteachers from other secondary schools in the Greater Manchester region spent a day at Mathew Moss, meeting with colleagues and students to talk about changemaking and what this means in practice.

LYNN PROVOOST

Assistant Headteacher, The Derby High School



We have been meeting, as school leaders and as teachers, with young people to talk about the sorts of things we’re doing in schools to make a change. It has been an incredible experience to walk through the corridors of this fantastic school, Matthew Moss, and see how engaged their young people are and the difference they’re making. It’s definitely something I want for our young people back at my school.

We work very closely with our young people, but these sessions give us the opportunity to ask big questions and think about how our young people could lead us in school – how we can change the way we interact with and educate our students, take their views into account, and co-create to make a better school and better education system.

Changemaker education has to be possible because I don’t think I could continue in this profession if it weren’t. We’ve got to take the opportunity to work with our young people, to make sure they’re equipped with skills they need to be successful in their lives, and also because they’re the ones who will make the change happen in the future – that’s our duty as educators.

JILL DAVIES

Principal, Liverpool Life Sciences UTC and The Studio School



We’ve managed to accomplish so much in these sessions in terms of thinking space. Meeting lots of wonderful people from other schools has made me realise that to really create change, it’s about empowering young people to be the changemakers. We’re there to facilitate that journey, but they’re the ones who are going to change the world.

The biggest takeaway for me so far is recognising that young people want the same thing from education that changemaker adults want. We’re not pulling in different directions. Students are saying, “This is what we want but we don’t know how to make that happen.” As adults, we’re also feeling the same. We’ve got the same priorities, desires, hopes, ambitions, and it’s liberating to know that, together, we’re super strong. This is where the real change will come, I think.

I fully subscribe to the ethos of changemaking. If you don’t subscribe, then why are you in education? We’ve got to be positive, we’ve got to be ‘glass half full’, and we’ve got to leave the education system in a better state than we found it. That’s what these New Capabilities for a New World programme sessions are allowing us to do.



Lynn (centre) talks to changemaker school leaders at a New Capabilities for a New World session. © Ashoka

ABOUT ASHOKA

Founded in 1980 by Bill Drayton in Washington DC, USA, Ashoka is an international non-governmental organisation dedicated to supporting social entrepreneurship. The name, Ashoka, was inspired by the Indian Emperor Ashoka, one of the world's earliest great social entrepreneurs. After unifying India in the 3rd Century BC Emperor Ashoka renounced violence and became one of history's most tolerant, global-minded and creative leaders, pioneering innovations in economic development and social welfare. The Sanskrit word *Ashoka* means the "active absence of sorrow".

To learn more, visit www.ashoka.org



ABOUT THE EDGE FOUNDATION

Based in the UK, the Edge Foundation aims to give all young people across the UK the knowledge, skills and behaviours they need to flourish in their future life and work. It collaborates with non-governmental organisations, government departments and academic establishments to gather evidence through research, trials and projects.

To learn more, visit www.edge.co.uk



MORPH WITH THE WIND: SHAPE-CHANGING BUILDINGS

STORMS OR HURRICANES CAN DAMAGE BUILDINGS IN A SINGLE INCIDENT. NEW ENGINEERING EFFORTS AT THE IOWA STATE AND KANSAS STATE UNIVERSITIES ARE CREATING BUILDINGS ADEPT AT WITHSTANDING THE EFFECTS OF WIND – NOT JUST THROUGH DESIGNING STRONGER STRUCTURAL SYSTEMS, BUT BY ENABLING THE BUILDINGS TO CHANGE THEIR SHAPE TO ADAPT TO CHANGING WIND CONDITIONS

ENGINEERING – AN OVERVIEW

Engineering is a very broad discipline and there are many specialties within it, which overlap with one another. Below are some of the most relevant for this article.

CIVIL ENGINEERING – the design and construction of infrastructure, such as buildings, bridges, roads, railways and utility networks. Structural engineering is a specialism of civil engineering, focusing on designing structures such as buildings and bridges

AEROSPACE ENGINEERING – generally involves the design and construction of aeroplanes, jets, gliders, autogyros, helicopters and more, but the skills needed to do this can be applied to other areas. Testing wind loads on various structures is one example

MECHANICAL ENGINEERING – one of the broadest areas of engineering involving control systems, structures, dynamics, fluid dynamics and thermodynamics

The exterior layer of a building – known as its façade – is an important element in its design and functionality. From an architectural standpoint, it is the part of the building that people will see, so its aesthetic traits are important. However, its main function from an engineering perspective is to protect the building from the elements, including the wind. While the impact of wind is considered in façade design, it is now believed the façade could have a much greater role to play in making the whole building as durable as possible, especially as buildings get taller and winds get stronger.

This issue is being addressed through a collaborative effort between Iowa State and Kansas State Universities. A team of engineers from both universities is creating Smart Morphing Façades, “Smorphacades” for short, which actively change their shape to reduce encounters with wind and subsequently wind-induced vibrations on the building. This leads to less stress placed on the underlying structure of the building, and a smaller range of vibrations, which means increased comfort for people inside. The team incorporates engineers from a range of disciplines, who combine their talents to bring the project to life.

THE TROUBLE WITH WIND

“Traditionally, fixed structures such as buildings are designed to be a specific and unchanging shape, with only crude estimates examining how they might respond to wind,” says Dr Alice Alipour, who leads the Iowa State side of the project. Buildings may be designed to be aerodynamic in the direction wind comes from most often, but the labyrinth of streets and buildings in any metropolitan area leads to erratic wind patterns, and these are being exacerbated by a changing climate.

Buildings are also becoming taller and more flexible, as lighter building materials and more sophisticated designs are developed, but wind-induced vibrations only get stronger and more serious with height. “The current solution to controlling this vibration is to place massive weights in buildings’ upper storeys,” says Dr Jared Hobeck, who leads the Kansas State side of the project. However, this solution entails substantial structural reinforcement and other costly measures, and is only effective for specific vibration frequency ranges. As hurricanes and tornadoes become stronger and more common, there are significant risks involved



in building tall and heavy buildings, and minimising structural damage is a key concern during the design process.

THE SMORPHACADE

The Smorphacade provides a solution for this issue. It consists of many movable components controlled by motors or similar devices, which perform a function similar to the flaps on a wing of an aircraft. Through changing their angle and position, they can make the building more streamlined in whatever direction the wind approaches from. “Smorphacades will be designed to change either the roughness of the façade, or the aerodynamics of any side of the building,” says Alice.

This proactive shape-changing will require a sophisticated control system, which is where Jared comes in. He is principal investigator for the Smorphacade control system, bringing with him a broad research background involving structures, wind vibration, and data-driven modelling. “The cyber-physical system we are developing uses a combination of wind sensors, optimisation algorithms and artificial intelligence to search for combinations of façade positions and wind flow conditions that limit building vibration,” says Jared. “Over time, the controller builds a ‘memory’ of the positions that work best for any particular wind flow condition.”

SCALE MODELS AND COMPUTER MODELS

Deciphering the exact shape of these devices, how they should be positioned on the building and how they react to different environmental conditions, forms the core challenge of the research project. “We use wind tunnels to test aeroelastic models,” says Alice. “These

models are designed to sway and twist in the wind in the same way the full-scale building would.” The models in question are about one-fiftieth to one-hundredth the size of the actual building, but represent the structural characteristics of a full-size building. Air flow in a wind tunnel can be precisely controlled, so the team can see exactly how the scale model responds to different wind patterns.

Jared also performs wind tunnel experiments, developing the network of vibration and pressure sensors that the Smorphacade’s algorithm relies upon to know how to adapt to different wind conditions. While very useful, these experiments can be expensive and time-consuming; therefore, simplified computer simulations can provide an efficient alternative to quantifying interactions.

Alice, with her structural engineering background, builds full scale numerical models of the building’s structural system to examine the impact of the changing wind loads on the building. This requires a detailed understanding of the structural characteristics of the building, including the materials used to build it, the building’s overall framework, and other loads it may encounter. Results from these simulations can then be used to help design the real-world Smorphacade system.

“We are very excited about the prospects of this project,” says Alice. “Our computational models, validated with extensive experimental tests, have highlighted that use of morphing façades to change the aerodynamics of the buildings provides a very effective way of reducing the wind-induced vibrations. Along the way we have made major contributions to the state-of-the-art of building design under wind events.”



A tornado simulator



A close-up of THOR, a computer used primarily for machine learning tasks

A BONUS PROJECT AIM

While mitigating wind-induced vibrations is the project’s primary function, the team also intends for the designs to be able to react to other environmental conditions by controlling shading or changing colour to save energy. For example, on hot sunny days, the façade can provide shade and turn a lighter colour to reflect heat from the sun, thereby reducing the energy required for cooling. How ‘cool’ is that?!

MEET SOME OF THE ENGINEERS!

The Smorphacade project involves a unique collaboration between structural engineers, wind engineers and control engineers, each of whom has their own integral role:

- **Structural engineers** understand building dynamics and ensure that plans meet current design requirements. They analyse the effects of reduced wind load on their buildings' underlying structure and assess buildings' performance and predicted life-cycle cost.

- **Wind engineers** understand interactions between building dynamics and flow conditions. They characterise wind loading, and how it differs with or without the Smorphacade, such as through testing scale models.

- **Control engineers** develop algorithms that can process information from sensors, and develop an active control mechanism that allows the Smorphacade to be adjusted as wind patterns around the building change.

Alice, Jared, and members of their team explain more about their own roles within the project, and what led them to where they are today. The project involves professors, PhD students, postgraduates and undergraduates.

DR ALICE ALIPOUR



*Cerwick Faculty Fellow;
Associate Professor,
Civil, Construction and
Environmental Engineering,
Iowa State University*

ROLE: *Lead Principal Investigator at Iowa State University and creator of the Smorphacade idea. Alice conducts performance-based designs and testing of scale models of tall buildings fitted with Smorphacades.*

WHAT INSPIRED YOU TO GET INTO ENGINEERING?

I have always been interested in math and physics, and as a child I was mesmerised by the construction sites of buildings and bridges. When I was old enough to enter college, engineering seemed a natural choice.

WHAT EXCITES YOU ABOUT THIS PROJECT?

The Smorphacade approaches the problem of wind affecting structures from a completely different perspective, by addressing the problem from its core. It will not only enhance the resilience of buildings but also help save energy, contributing to sustainability efforts. It should be a win-win development for the design of tall buildings.

WHAT LED YOU TO STUDY CIVIL ENGINEERING?

Natural hazards engineering is a major interest of mine, and has been the focus of much of my education and research. By studying the impacts of natural hazards on the built environment, we can modify the design of buildings and structures to improve the resilience of communities exposed to these hazards.

YOU ARE INVOLVED IN WISE (WOMEN IN STEM EDUCATION), SCIENCE BOUND (FOR STUDENTS OF COLOUR), AND THE EARTHQUAKE ENGINEERING RESEARCH INSTITUTE STUDENT CHAPTER. WHY ARE YOU PASSIONATE ABOUT THESE PROGRAMMES?

I am a true believer in diversity within the design and management of our built environment. The infrastructure we build should serve everyone in society, so we need a workforce that reflects the society we serve.

WHAT DRIVES YOUR PASSION FOR MENTORING?

I have always thrived on offering close mentorship and support to a diverse group of students. In particular, I have found involving them in research and professional development activities to have a lasting impact on their careers.

TOP TIP

Never stop dreaming. The world's most challenging problems need people who can think outside the box.

PURSuing A CAREER IN ENGINEERING

- Different engineering degrees have different requirements, but a strong background in mathematics is almost always beneficial, followed by physics, chemistry and computer science.

- The scope and scale of engineering brings with it good job prospects. Jared says the majority of his students have a job offer before they graduate with their bachelor's degree.

- There are lots of websites outlining the wide range of engineering careers. For example, the Institute of Structural Engineers provides a breakdown of what structural engineers do, and includes an engaging video: www.istructe.org/become-a-structural-engineer/what-is-an-engineer

- This is Engineering helps make the link between solving world challenges and the

breadth of careers in engineering:
www.thisisengineering.org.uk

- According to Salary.com, an engineer in the US can earn between \$64,820 to \$159,490, though Jared points out that this can be dependent on many factors, such as location, type of industry, experience and qualifications.

DR PARTHA P. SARKAR



Professor

Department of Aerospace Engineering;
Department of Civil, Construction, and
Environmental Engineering (courtesy),
Iowa State University

ROLE: Design, build, and test the Smorphacade, to evaluate its performance in mitigating wind vibrations of a building. This involves testing a scaled model in a wind tunnel, facilitating structural analysis, and selecting the most effective configurations.

WHAT EXCITES YOU ABOUT THE SMORPHACADE PROJECT?

I enjoy the opportunity to test the bold concept of a smart building façade that can morph and modify itself in real time. In nature, tall trees bend and fold their leaves to reduce their aerodynamic drag in high winds. Developing a man-made building that can dynamically react to wind in a similar way is an exciting challenge.

YOU HAVE RECENTLY BEEN NAMED A FELLOW OF THE AMERICAN SOCIETY OF ENGINEERS AND A FELLOW OF THE STRUCTURAL ENGINEERING INSTITUTE. WHAT DO THESE ACCOLADES MEAN TO YOU?

To qualify for these fellowships, I had to show significant contributions to research, education and outreach in my areas of expertise, as well as service to these societies and involvement in other professional activities. My long-standing membership of both organisations and strong support from my colleagues helped me earn these distinctions. These awards mean the whole world to me because they recognise my

accomplishments and contributions to my profession, which I am so proud of.

WOULD YOU RECOMMEND A CAREER IN ENGINEERING?

I certainly would. Through innovation, analysis, design and building, engineers solve a multitude of the technical, environmental and social problems that the world faces. There are different disciplines within engineering depending on one's skills and interests. Jobs are abundant, average salaries are great and there is a good growth prospect. Tomorrow's engineers will face many challenges to solve, related to climate change, cybersecurity and population growth.

TOP TIP

Engineering requires a strong background in science and math, problem solving, and sometimes hands-on skills. I recommend sharpening these skills early on in high school, which will also help you recognise where your talents and interests lie. Read up on different engineering disciplines, what they entail, and what they can achieve.

DR BEHROUZ SHAFEI



Cerwik Faculty Fellow;
Associate Professor, Department
of Civil, Construction, and
Environmental Engineering;
Department of Materials Science and
Engineering, Iowa State University

ROLE: Systematically study how buildings equipped with Smorphacades can be configured to a satisfactory structural performance, alongside mitigating the risk of wind hazard. This involves ensuring new building systems meet code-specified requirements and are optimised in terms of material and construction efficiency.

WHAT IMPACT WILL THIS PROJECT HAVE?

The proposed Smorphacades introduce a radical transformation in how buildings are designed and configured to resist extreme wind events. This cutting-edge innovation will have a lasting positive impact on the safety and performance of buildings in areas prone to severe hurricanes and tornadoes.

HOW DID YOU CHOOSE WHICH AREA OF ENGINEERING TO STUDY AT UNIVERSITY?

My BSc focused on civil engineering, which included components of structural engineering. After graduating, I decided to focus on structural engineering for my MSc and PhD, to pursue my passion for the performance and risk assessment of structures.

WOULD YOU RECOMMEND A CAREER IN ENGINEERING?

Yes, for sure. Engineering is a broad domain with several disciplines that can directly contribute to improving the quality of our built environment. There are ample opportunities to follow your

own area of interest, spanning theoretical or hands-on experimental work.

TOP TIP

Get involved in research projects as early as you can, even at high school if possible. Personally, early engagement helped me establish my own research career. Research also helps you learn how to think systematically, an important skill for problem-solving, both in engineering and elsewhere in life.

DR JARED HOBECK



*Burk-Ice Keystone Research Scholar
Assistant Professor of Mechanical
Engineering, Director of the Multifunctional
Structures Lab, Alan Levin Department
of Mechanical and Nuclear Engineering
Kansas State University*

ROLE: *Principal Investigator at Kansas
State University. Jared develops the
Smorphacade control system and actuator
mechanisms. He also designs, builds and
tests aeroelastic building models outfitted
with a Smorphacade system.*

WHAT SKILLS DO YOU BRING TO THIS PROJECT?

My background is in multidisciplinary research, including multifunctional structures, system dynamics, flow-induced vibration and data-driven modelling.

WHAT EXCITES YOU ABOUT THIS PROJECT?

I am excited by the multidisciplinary nature of this project, and the challenge associated with developing a controller for such a complex and highly dynamic system.

DID YOU ALWAYS WANT TO BE AN ENGINEER WHEN YOU WERE YOUNGER?

No, though science was my favourite topic in school. I did not enjoy math, but was excited to see what could be accomplished with it, and understood its necessity within engineering. My academic career happened almost by accident. I had no interest in graduate school until a particular research project during my undergraduate studies, no interest in a PhD until I started my master's, and no interest in becoming a professor until towards the end of my PhD.

YOU WERE INTERVIEWED BY FOX TELEVISION ABOUT YOUR RESEARCH ON PIEZOELECTRIC GRASS. WHAT IS PIEZOELECTRIC GRASS?

Piezoelectric grass is artificial grass made with a unique material (piezoelectric ceramic) that produces a voltage when it bends.

DO YOU THINK IT IS IMPORTANT FOR SCIENTISTS TO COMMUNICATE TO THE PUBLIC, SUCH AS THROUGH TV OR RADIO?

Yes. I think any mechanism that introduces young people to STEM or shares knowledge with society is important. Gathering knowledge only to keep it to oneself is worthless.

TOP TIP

Never feel limited by your situation, and don't worry about making big career plans. Just pursue your interests one step at a time. Be prepared for those interests to change, and follow them as they do, even if the challenges you face seem too big. The reward is usually much bigger.

KHALID ABDELAZIZ



*PhD Candidate and
Graduate Research Assistant,
Multifunctional Structures Lab,
Alan Levin Department of Mechanical
and Nuclear Engineering,
Kansas State University*

ROLE: *Develop computer simulation
models and Smorphacade control
algorithms.*

WHAT SKILLS DO YOU BRING TO THIS PROJECT?

I have experience with computational modelling and simulation techniques, engineering optimisation and machine learning. My background involves both academia and industry. During this project I have started learning about many more areas, and I believe my ability to learn new skills is my most important talent.

WHAT MOTIVATES YOU TO WORK ON THIS PROJECT?

At first, I was excited by the innovative nature of the idea, but was also concerned about its feasibility. As I kept working, I grew increasingly motivated by positive signs from our initial simulation studies and our preliminary experimental studies. Now we know the Smorphacade is feasible, we are trying to make it as effective and practical as possible.

WHAT DID YOU WANT TO BE WHEN YOU WERE YOUNGER?

I think in some form I always wanted to be a researcher, but this only became clear during my master's degree when I started doing scientific research. My personality

always revolved around finding better solutions to the status quo. Being a researcher allows me to do just that while also making a living.

WHAT LED YOU TO STUDY MECHANICAL ENGINEERING?

I learned web design and computer programming in my early high school days, and was hired as a junior web developer not long after. I first majored in computer science, the logical choice, but found it uninteresting since I already knew its contents. My mother advised me to switch to another field where my knowledge could be useful, so I picked mechanical engineering because I also adored machines. That advice from my mother shaped my future in ways I could never imagine.

WOULD YOU RECOMMEND A CAREER IN MECHANICAL ENGINEERING?

I would. It is one of the most versatile engineering disciplines, and has a function within virtually every industry. The discipline also fosters analytical thinking and a problem-solving mindset, that can help make one's daily life more organised.

SMRITHI HAREENDARAN



PhD student,
Department of Civil, Construction
and Environmental Engineering,
Iowa State University

WHAT SKILLS DO YOU BRING TO THE TEAM?

I am a structural engineer and proficient in analysis and design software and the codes and standards needed for the design of steel and concrete buildings. This enabled me to develop a novel analytical framework for the structural performance assessment of tall buildings under extreme wind loads. I also have knowledge of machine learning that helps me implement deep learning techniques for the prediction of buildings' structural behaviour under wind loads.

DID YOU ALWAYS WANT TO BE AN ENGINEER WHEN YOU WERE YOUNGER?

When I first considered university, I wanted to be an architect, because I was interested in the aesthetics of structures. As I was finishing school, I realised I was also very interested in analytical problem-solving, and so pursued civil engineering, as this combined both my creative and problem-solving interests.

HOW DID YOU CHOOSE WHICH AREA OF ENGINEERING TO STUDY?

During my bachelor's degree in civil engineering, my favourite subjects always involved structural analysis and design. In my final year I worked on the development and design of a reinforced concrete bridge. I thoroughly enjoyed this project and was eager to learn more, which led to me pursuing a master's and PhD in structural engineering.

WOULD YOU RECOMMEND A CAREER IN STRUCTURAL ENGINEERING?

Yes, I certainly would! A structural engineer is often involved in highly creative and multidisciplinary projects, working in areas such as the energy, industrial, or green building sectors. It is a highly innovative career which can provide opportunities to give back to the community, such as through involvement in sustainability-based design projects.

FANGWEI HOU



PhD student,
Iowa State University

ROLE: Design and perform a series of wind tunnel tests to validate the effectiveness of the Smorphacade system.

YOU HAVE BEEN AWARDED THE REX AWARD FOR OUTSTANDING RESEARCH ACCOMPLISHMENTS. WHAT HELPED YOU TO ACHIEVE THIS RECOGNITION?

I think hard work and passion for the work I was doing helped me get the award. I greatly appreciated the support of Dr Sarkar and Dr Alipour on my research; without them, I would not have got the award.

WHY DID YOU CHOOSE TO STUDY AEROSPACE ENGINEERING?

I chose aerospace engineering for my undergraduate degree because I dreamed that one day I could become an aircraft designer. I like how engineering can help us solve real-world problems.

TOP TIP

Be creative. Engineers are always solving problems, and creativity is a vital component of this.

DIKSHANT SAINI



Postdoctoral Scholar,
Iowa State University

WHAT WILL THE SMORPHACADE ENABLE ENGINEERS TO DO?

The Smorphacade is an interesting concept. We normally design buildings to be a specific shape, but this is not always effective at mitigating wind vibrations given that wind speed and direction is constantly varying. With the Smorphacade, engineers will be able to optimise buildings' shapes to weather any storm, through reducing the wind-induced vibrations of the buildings.

WHAT SKILLS DO YOU BRING TO THIS PROJECT?

I have a strong background in structural dynamics and mechanics. During my PhD, I voluntarily learnt concepts that directly integrate into the Smorphacade project, such as wind engineering and flow aerodynamics.

WHY DID YOU CHOOSE TO STUDY CIVIL ENGINEERING?

I chose to study civil engineering and specialised in structural engineering during my PhD. When I was young, my dad would take me and my sister to visit the aqueducts in my city, to show how the river passes through the canals and tunnels. I was intrigued by the design and its function, and this began a lifelong interest in the discipline.

WOULD YOU RECOMMEND A CAREER IN CIVIL ENGINEERING?

Without a doubt. A civil engineer can directly help communities to protect themselves against natural or man-made hazards. Civil infrastructures such as bridges, buildings, and waterways are fundamental to a nation's growth and economy.



UNEXPECTED WAYS THAT PAINT PREVENTS CORROSION

OUR MODERN LIFESTYLES DEPEND ON THE MATERIAL OBJECTS AROUND US REMAINING STRONG AND FREE FROM DAMAGE. PROTECTIVE PAINTS AND COATINGS ARE EFFECTIVE AT PREVENTING CORROSION DAMAGE, BUT HOW THEY DO THIS – AND HOW THESE MECHANISMS CAN BE OPTIMISED – ARE LESS WELL UNDERSTOOD. THE SUSTAINABLE COATINGS BY RATIONAL DESIGN (SUSCORD) PROJECT CONNECTS MATERIALS SCIENCE ACADEMICS WITH COMMERCIAL SCIENTISTS TO TACKLE THESE QUESTIONS

TALK LIKE A MATERIALS SCIENTIST

ACTIVE INGREDIENT — a component of a material that is responsible for a particular effect or property

CORROSION — the gradual destruction of a material (usually a metal) and its properties (like strength) by chemical or electrochemical reaction with its environment

THERMODYNAMICALLY STABLE — the state of a material or system being in chemical balance with its environment

ELECTROCHEMICAL — a reaction that involves both electrical and chemical changes

EMPIRICAL DESIGN — an approach based on evidence and observation that does not try to fully understand how things work (e.g., Kepler's Laws that describe how the planets orbit the sun – predating Newton's laws of gravity)

OXIDISED — combine chemically with oxygen

NANOCOMPOSITE — a composite combines several different materials to optimise its useful properties; in a nanocomposite, some components are at the nano scale (less than 1 micron in size)

OXIDATION — the loss of electrons during a chemical reaction by a molecule, atom or ion. See BBC Bitesize for a more detailed explanation: www.bbc.co.uk/bitesize/guides/z7rswty/revision/1

PIGMENT — a substance that gives paint a useful function like colour, hardness, and resistance to weathering and corrosion

POLYMER — a substance (such as a plastic) made up of many similar molecular units bonded together

RATIONAL DESIGN — an approach that makes predictions based on understanding and modelling how things work (e.g., Einstein's Theory of General Relativity that explains gravity)

From tower blocks to cargo ships, suspension bridges to wind turbines, modern society depends on metal structures that resist corrosion and remain dependable for years. Corrosion-protective paints make this possible, but there are gaps in our knowledge that prevent us from explaining how exactly such paints work. Professor Stuart Lyon and Dr Yanwen Liu, from the University of Manchester, and Dr Andy Parnell, from the University of Sheffield, are part of a research team that has partnered with Anglo-Dutch coatings company AkzoNobel to fill these gaps using a wide range of innovative scientific techniques.

PAINT AND CORROSION

“Aside from its decorative aspects, paint can have many functional qualities,” says Stuart. “In the SusCoRD partnership, we’re focusing specifically on coatings that protect metal surfaces from corrosion.” Paints typically contain a complex mix of ingredients, each with its own purpose. These can include binders that help “glue” the paint together, pigments



THE SUSCORD PROSPERITY PARTNERSHIP
Sustainable Coatings by Rational Design



RESEARCH PROJECT

Understanding “how paint works”, through addressing fundamental research questions concerning corrosion-protective coatings



FUNDERS

AkzoNobel, Engineering and Physical Sciences Research Council (EPSRC)

that give the paint its colour and other useful properties, solvents that help the ingredients mix properly and many others. “The binder is generally a cross-linking organic polymer, and the functional pigments are often on the nano scale,” says Yanwen. “Paint is therefore a sophisticated, complex and functional polymer composite material.” The team aims to understand how the nano-scale properties of paints define their overall function.

Corrosion is a process in which a material reacts with its environment in a way that leads to a loss of function, typically the material’s strength. “Interactions with water molecules can cause metal to corrode, turning its atoms into ions that release electrons,” explains Andy. “These electrons enter a second chemical reaction, usually involving the consumption of oxygen. Corrosion is, therefore, an electrochemical reaction, because both chemical and electrical processes are involved.”

PROTECTING AGAINST CORROSION

Corrosion occurs because the thermodynamically stable ‘natural’ state of a metal is to be oxidised. Metal ores are mined in their oxidised state, and energy is added in the refining process to reduce the ores to the metal. Over time, however, metals will corrode naturally and return to their most stable, oxidised form, losing their useful properties in the process. “Because corrosion

is an electrochemical reaction and needs water and oxygen, it can be controlled by removing these reactants and/or by stopping the flow of current,” says Stuart. “It is possible to remove oxygen from closed systems, such as in central heating or engine-cooling systems, but for most systems open to the air, another protection method is needed.”

There are three main theories about how corrosion-protective paints work:

- The paint acts as a physical barrier between the metal and any oxygen or water in the environment.
- The paint acts as an electrical insulator, slowing the flow of current that drives the electrochemical reaction of corrosion.
- There are active ingredients within paint that gather at sites where corrosion has begun and inhibit further corrosion.

It is likely that all three of these processes play a part in corrosion protection. The team is interested in discovering which are most significant and how the processes can be optimised to produce the most corrosion-protective paint possible.

TESTING CORROSION-PROTECTIVE PAINTS

Until recently, most research depended

on empirical design, a scientific philosophy that emphasises the importance of evidence to build conclusions. “This ‘trial and error’ approach uses existing knowledge and experience to make a first approximation to what might work and then tests this approximation,” explains Yanwen. However, this becomes impractical when testing corrosion-protective paints because there is a need to prove that these paints are effective for decades. “We develop ‘accelerated’ tests in the lab, which mimic the effects of decades-long exposure to the environment in a much shorter time,” says Andy. “However, we have to accept that these aren’t completely realistic and need to find ways to account for that.”

This means that developments in the field can take time, especially if there is a need to develop completely new materials or systems where there is no existing knowledge base to draw on. “For instance, it took 20 years to find an effective replacement to lead-based paints to protect steel from corrosion,” says Stuart. “We are still trying to find an optimum substitute for chromate, currently used in paints, to suppress corrosion of aluminium aircraft.” While they are successful ingredients for corrosion protection, lead- and chromate-based paints present significant hazards to human health.



SOLUTIONS THROUGH RATIONAL DESIGN

Fortunately, the rise of molecular science and computer technology is helping address this time problem. As an alternative to empirical design, 'rational design' aims to discover how substances work at a fundamental level and then model potential combinations, rather than just observing their effects through trial and error. Once ingredients' properties are understood – including how they interact with one another – this information is plugged into computer models, which can then simulate how different combinations of ingredients behave in different environments over time. "This approach helps reduce the number of formulations to trial in the real world, because the computer models inform us quickly about many formulations that definitely won't work," says Yanwen. "The models also help suggest changes to formulations that may use better, cheaper or more environmentally sustainable ingredients without affecting performance."

While the primary roles of the individual ingredients in paints are well-understood, the behaviour of the ingredients when combined is what these models aim to test. "These ingredients interact in ways that are currently not predictable," says Andy. "Aside from providing colour, we know that certain types of pigment provide corrosion protection in some manner. However, they have many different properties and interactions that affect the level of protection they convey."

The team's research suggests that the third theory of active ingredients gathering at sites where corrosion has begun plays a significant

role. "The pigments dissolve in the presence of water, and their active ingredients migrate to the corrosion sites and inhibit the reaction," says Stuart. "This process is influenced by the shape, size and distribution of pigment particles, as well as their interactions with other pigments and solvents, method of application, environmental conditions and so on."

TESTING METHODS

Understanding how all these materials behave and interact at a fundamental level is no easy task. "We need to study every aspect of the coating in isolation and when attached to metal," says Yanwen. "This is difficult because analysis of all the different components in the coatings requires different techniques and tools." In addition, the team has to find ways to examine exactly what happens where the metal meets the paint, where corrosion begins, without disrupting the reactions taking place there.

Fortunately, the team has several high-tech analytical methods at its disposal, from the fields of materials science, surface science and electrochemistry. "We use high-resolution analytical electron microscopy, X-ray tomography and atomic force microscopy to directly observe the materials," says Andy. "Ellipsometry studies how the paint interacts with surfaces, while X-ray and neutron scattering examine how water moves within the substance." Several other microscopy techniques help study the electrochemical changes taking place.

Computing is vital throughout. "Mathematical models help us understand how corrosive and anti-corrosive substances behave," says Stuart. "In addition, AkzoNobel has many years of corrosion test data for

their products, which we're supplying to machine learning algorithms to identify how complex combinations of factors relate to performance."

REVELATIONS

The team has made considerable progress in discovering what works and what does not in terms of corrosion protection. While the first of the three theories outlined earlier may seem the most 'obvious', there is mounting evidence that it plays only a minor role. "It has been known for some time that paint doesn't effectively block the migration of water and oxygen, which is why decorative wall paint is useless for preventing corrosion of steel," says Yanwen. "So, this method is not how paint works to protect against corrosion."

There is more evidence for electrical resistance, the second theory, as an effective corrosion blocker. "However, our research suggests this resistance does not come from the paint alone, but from the paint-metal interface, which is where the corrosion starts," says Stuart. "Our current focus is on testing this hypothesis." This points towards a combination of the second and third theories as defining corrosion protection.

The team has made other insightful discoveries. "It might be assumed that a greater concentration of anti-corrosion pigment would lead to a more effective coating," says Andy. "However, we've found that high concentrations leach out of the paint faster, giving the coating a shorter lifetime. Based on these findings, we're developing a computer model to predict the optimum amount of active ingredient."

ABOUT MATERIALS SCIENCE

Materials science involves the design, study and discovery of new materials. This broad scope means that it interacts with many other STEM disciplines. “Materials science provides the link between understanding a material’s microstructure at the nanoscale, to discovering how these properties affect a material’s function at the macroscale,” says Andy. “Understanding these properties involves using tools such as imaging, characterisation and simulation. Additionally, materials scientists may use this understanding to create new useful materials through synthesis, processing, manufacture or modelling.”

WHY IS MATERIALS SCIENCE IMPORTANT?

“Materials are central to the socio-economic well-being of the country,” Stuart explains. “Materials scientists and engineers help to develop

the materials required for new products, improve and lower the cost of manufacturing routes and enhance the performance of existing materials. They consider the environmental impact and sustainability of their products, for example, by replacing materials that rely on scarce elements or are hazardous to health. They discover how to optimise the selection of materials and create sophisticated models and databases from which properties can be predicted.”

HOW DO MATERIALS SCIENTISTS FIT INTO THE SUSCORD PARTNERSHIP?

“The problem is too complex for a single expert to cover, so a multidisciplinary approach is essential,” says Yanwen. “Our academic research team consists of chemists, physicists, materials scientists, microscopists, electrochemists, mathematicians, computational modellers and corrosion experts. This is supported from the AkzoNobel side by

paint chemists, polymer physicists, formulation chemists and experts in testing and evaluation and in industrial paint making. Finally, and probably most importantly, is Dr Jane Deakin, our project manager, who supports the team, reminds us of our overall aims and objectives, organises meetings and generally keeps us on our toes.”

WHY SHOULD YOUNG PEOPLE CONSIDER A CAREER IN MATERIALS SCIENCE?

“Materials scientists or engineers are always in high demand and are relatively well rewarded,” says Stuart. “They may be employed in many sectors, with careers in manufacturing, research, product development, consultancy or education. Areas that are in need of materials scientists include advanced transport systems, healthcare, energy generation, environmental protection and electronics.”

EXPLORE CAREERS IN MATERIALS SCIENCE

The communities of all the universities participating in the SusCoRD project are strong in materials science and manufacturing. Manchester has the largest and most diverse materials department in the UK, while Sheffield and Liverpool have strong manufacturing histories.

During the annual British Science Week, these departments engage in public outreach, which can be a good opportunity to learn more.

Nuffield Research Placements are a valuable way to learn more about STEM, including materials science, through gaining research skills and enhancing university applications:

www.nuffieldfoundation.org/students-teachers/nuffield-research-placements

The Institute of Materials, Minerals and Mining (IoM3) provides a wide range of relevant outreach activities and resources for school students:

www.iom3.org/careers-learning/schools-outreach.html

According to Payscale, salaries for early career materials specialists in the UK are around £32,000. This is the higher end of engineering and science professions and increases significantly as people progress to more senior roles.

PATHWAY FROM SCHOOL TO MATERIALS SCIENCE

For a standard entry into materials science, the researchers recommend taking A-Levels or equivalents in physics, chemistry and maths, as well as biology if possible. “As materials science is not taught specifically in schools, university courses start at the basics,” says Stuart. “Most universities also offer entry routes via BTEC level 3 in maths and science as well as access and foundation routes to undergraduate study.”

Aside from university, there are also BTEC courses available for materials science, which can lead to opportunities within the manufacturing industry where a strong technical knowledge base is essential.

MEET THE TEAM



PROFESSOR STUART LYON

AKZONOBEL PROFESSOR OF CORROSION CONTROL, DEPARTMENT OF MATERIALS,
UNIVERSITY OF MANCHESTER, UK

FIELDS OF RESEARCH: MATERIALS SCIENCE, ELECTROCHEMISTRY AND
CORROSION PROTECTION

As a child, I was interested in everything around me, from the natural world to functional man-made objects. I was always taking things apart to see how they worked. I remember I wanted a wristwatch so badly at the age of nine and had to promise never to take it apart before my parents would buy it! My father was a mechanical engineer and often called me into the garage to help him maintain his car with the help of my “small fingers”.

Professors have two main roles. The first is to teach what we know to students. The second is to undertake research to make new discoveries, and then teach these too. Research does not just involve time in the lab, but also securing finances by pitching ideas to companies or government funders, recruiting and supporting researchers, and navigating the publication and dissemination of results.

I graduated with a degree in metallurgy and materials science and then continued with a

PhD. Despite a severe economic recession when I completed this, I was fortunate to secure a post-doctoral position working in corrosion prevention, and then started climbing the academic ladder over the following 25 years.

I don't undertake any research myself – this is undertaken by postgraduate students or more experienced post-doctoral researchers. As a principal investigator, I lead and manage a team of investigators and researchers who undertake the work. I ensure that individual projects are going well and milestones are being met. I also spend time with my own researchers who I supervise to discuss how things are going.

Academia can sometimes be lonely, but the remarkable thing about SusCoRD is that we have built a genuine partnership between a large multinational enterprise, AkzoNobel, and three UK universities across four disciplines. It's really exciting to work with such a talented and knowledgeable group of people.

The most frustrating aspect of research is usually its slow pace. We're all desperate to prove our great ideas, but time is needed to set up experiments correctly and develop the skills needed. You must have faith in your ideas and continue trying.

I'm fascinated by materials and how they can be scientifically designed and then engineered into products with almost magical properties. The fine-scale structure of a material generally controls its property and investigating this to the almost atomic level is so intriguing.

I enjoy physical activities such as hiking, walking my dog and cycling. I also love upgrading my house – for instance, I installed a new bathroom last year. And, as you might expect, I always do the painting in my house!

THE TEAM'S TOP TIPS

01 The world needs scientists for every aspect of society. Keep your curiosity and explore the world, with your eyes or with microscopes!

02 There are no dumb questions, so don't be afraid to ask. Whether about scientific processes or how people got to where they wanted to be.



DR YANWEN LIU

RESEARCH FELLOW, DEPARTMENT OF MATERIALS, UNIVERSITY OF MANCHESTER, UK

FIELD OF RESEARCH: CORROSION PROTECTION OF METAL SUBSTRATES BY COATINGS AND INHIBITORS

When I was young, I was very interested in chemistry. I was also keen to understand how things gradually decay over time, such as metal fences. Later, I understood that what I was watching was the corrosion of the metal beneath the paint.

I obtained a degree in petrochemical engineering and worked in the industry for a while, developing lubricants and corrosion-inhibiting oils, before undertaking a PhD at the University of Manchester. During my PhD, I investigated how to slow the corrosion of aerospace aluminium alloys through uncovering the mechanisms at play that defined the functions of various pigments within coatings. After I completed my PhD, I continued working in the same area, beginning work on projects sponsored by AkzoNobel from 2012, initially to investigate alternatives to toxic chromate-based paints in the architecture and aircraft industry. This eventually led to me becoming a co-investigator on the SusCoRD project.

My co-investigator role involves the application of advanced analytical microscopy and spectroscopy to understand the physical and chemical degradation processes of metals and coatings. I also use X-ray tomography for analysis of degradation and leaching pathways.

The project is providing an invaluable way to understand why coatings fail with time, and

how to prolong the life expectancy of coatings to protect the metal for as long as possible. The global cost of corrosion is huge, so finding ways these costs could be significantly reduced is rewarding. Moreover, our research is uncovering more environmentally friendly coatings, which will be necessary for a sustainable future.

I find the most challenging part to be balancing the scientific process alongside industry needs.

The former benefits from knowledge sharing and lengthy investigation, while the latter requires confidentiality and rapid progress. However, through effective communication with our industry counterparts, our work becomes effective and efficient.

We are able to publish our findings not only from lab observations and results but also from coatings used in the real world in real time, which gives a real understanding of how coatings actually degrade, compared to simulations and models. This data is very precious for scientific communities.

I love to relax by reading at home or going for walks in the countryside.



DR ANDREW PARNELL

RESEARCH FELLOW, DEPARTMENT OF PHYSICS AND ASTRONOMY, UNIVERSITY OF SHEFFIELD, UK

FIELD OF RESEARCH: MATERIALS PHYSICS

I've always been adventurous and loved exploring the outdoors on my mountain bike when I was younger. I also had a fascination with technology and spent hours tinkering with computers and radios. As a teenager, I had a strong interest in amateur radio, and a friend and I used to repurpose radio equipment from the police and

make our own broadcasts. I became a member of an amateur radio club that let me connect with and learn from many amazing and experienced members. I have a powerful memory of one of the members demonstrating using a laser as a potential communication method, by spraying aerosol in the dark and lighting the room with the laser.

Having studied chemistry, physics and maths at A-level, I took a degree in physics, which made me aware of the many applications of science, including an experimental project on squeezed light that went on to be published. After my degree, I was fortunate to be accepted for a master's course in nanoscale science and technology, where I learnt everything from self-assembly to organic electronics. This gave me a great generalist skillset, and one project in particular led me to undertake a PhD on responsive polyelectrolyte surface grafted brushes. I then went back to the Department of Physics at Sheffield and have since been promoted to a lecturer. My projects have often involved the industry and I've worked with talented individuals from many multinational companies.

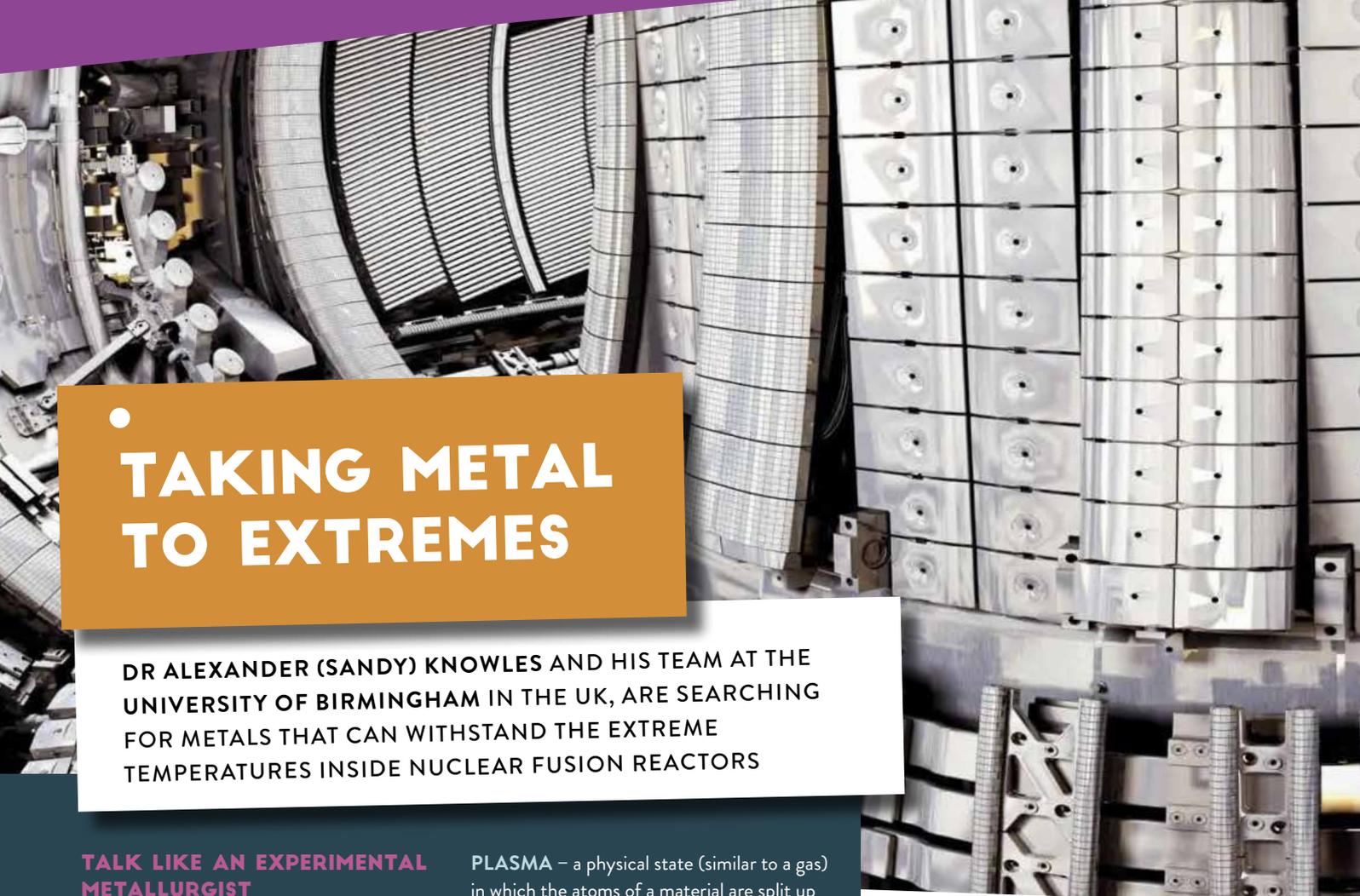
I work on the surfaces and interfaces work package, which aims to understand how protective coatings work by examining the paint-metal interface in detail. There's no such thing as a typical day, which helps make my career fun! I help plan, run, troubleshoot and discuss the results that we get.

The return to the lab and seeing my colleagues again, after the worst of the COVID-19 pandemic had passed. The pandemic was a difficult moment to get through.

Learning new experimental techniques can be challenging as it involves reading and re-reading textbooks and academic papers to best understand the possibilities and pitfalls of new techniques.

The variety and breadth of materials physics is vast, covering everything from paints and coatings to organic solar cells. This makes the science that I do relevant to a whole array of different arenas, which is immensely rewarding.

I love cycling and walking in the Peak District, as well as spending time with my wife and daughter.



TAKING METAL TO EXTREMES

DR ALEXANDER (SANDY) KNOWLES AND HIS TEAM AT THE UNIVERSITY OF BIRMINGHAM IN THE UK, ARE SEARCHING FOR METALS THAT CAN WITHSTAND THE EXTREME TEMPERATURES INSIDE NUCLEAR FUSION REACTORS

TALK LIKE AN EXPERIMENTAL METALLURGIST

NUCLEAR FUSION – joining of atoms to generate energy ($E = mc^2$), typically tritium + deuterium (hydrogen isotopes with excess neutrons) → Helium + neutron + energy

NUCLEAR FISSION – splitting the atom, where a heavy unstable element such as uranium is split with a neutron into multiple smaller elements releasing neutrons + energy ($E = mc^2$, which states that a change in mass during a nuclear reaction releases energy)

PLASMA – a physical state (similar to a gas) in which the atoms of a material are split up into separate electrons and nuclei

NANO-PARTICLE – term for a particle between 1 and 100 nanometres in size. In comparison, a human hair is ~70,000 nm thick

ALLOY – a metal made from a combination of multiples elements

SUPERALLOY – an alloy capable of withstanding extreme stresses, such as extreme temperatures

When you cook something in the oven at home, what kind of temperature do you set the dial to? Imagine what would happen if you could somehow crank up the heat from 200 °C to 2,000 °C. Your oven would melt down into a lava-like puddle (never mind the burnt chips) as the melting temperature of steel is around 1,500 °C. Clearly, some metals are just not designed for these kinds of extremes.

At the University of Birmingham, Dr Alexander (Sandy) Knowles and his team of metallurgists are experimenting with new materials and pushing them to their limits. They want to find a metal with which to build nuclear reactors, as they hope nuclear fission and fusion will provide us with cheap, clean energy that can help to prevent climate change.

WHAT IS THE DIFFERENCE BETWEEN FISSION AND FUSION?

Nuclear energy is a little like alchemy. The end product might not be gold, but it is all about transforming one element of the periodic table into another. The difference between fission and fusion is about which direction along the periodic table the transformation takes you.

Fission is the reaction that humans have cracked already and involves splitting the nucleus of a very heavy element to create smaller ones. Huge amounts of energy are released in the process, whilst no carbon dioxide is emitted. As Sandy explains, “One Coke can’s worth of nuclear fuel could produce your entire lifetime’s electricity use, carbon-free! Fission is a low-carbon technology we can deploy widely now to address climate change.”

When it comes to fusion, scientists and engineers are still reaching for the stars. Fusion is the process that happens inside a star like the Sun, where small nuclei are squeezed together to make larger ones. It could be even more beneficial than fission because the input fuel (hydrogen) is almost limitless, and the reaction waste products are not radioactive. However, creating an artificial Sun on Earth is difficult. For fusion to work, the hydrogen needs to be heated to extreme temperatures to form a plasma, and this is where Sandy’s extreme metals come in.

HOW DO YOU CONTAIN PLASMA AT 150 MILLION DEGREES?

The temperature at the middle of a fusion reactor is ten times hotter than the centre of the Sun. It needs to be this hot because, on Earth, we do not have the massive gravity of the Sun which helps confine the plasma and promote fusion. Sandy explains, “The plasma is held in place by huge magnetic fields from superconducting magnets.” However, at some point there needs to be a physical barrier, and the temperature here could still be hotter than molten lava.

Tungsten is the metal with the highest melting point of all, but there is a problem. When the super-hot plasma spits out neutrons, this radiation can damage the metal. Sandy is looking for a way to reinforce tungsten using nano-particles and testing his new ‘superalloys’ in oven-like furnaces that go up to 2,000 °C.

JET fusion reactor
(Photo credit: www.ccfе.ukaea.uk)



DR ALEXANDER (SANDY) KNOWLES

Associate Professor in Nuclear Materials, UKRI Future Leaders Fellow & Royal Academy of Engineering Associate Research Fellow, University of Birmingham, UK



FIELDS OF RESEARCH

Materials Science, Experimental Metallurgy, Microscopy



RESEARCH PROJECT

Creating and experimenting with new materials for use in extreme environments, such as nuclear reactors



FUNDERS

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EXPLORE CAREERS IN EXPERIMENTAL METALLURGY

- Sandy recommends Discover Materials as a “fantastic new and growing initiative that delves into what materials science is all about and the latest exciting research”: www.discovermaterials.co.uk
- UK-based Prospects provides useful information on the types of careers and responsibilities in metallurgy: www.prospects.ac.uk/job-profiles/metallurgist
- Read more about metallurgy training, jobs and salaries in the US at: www.environmentalscience.org/career/metallurgist

As well as testing the materials, it is also important for the metallurgists to understand why they behave as they do. By examining the metals with advanced microscopes, they are able to see how the atoms themselves are arranged and mixed. Sandy explains, “We use scanning electron microscopy (SEM) as well as transmission electron microscopy (TEM). SEM looks at the surface, whilst TEM looks through the material and allows greater resolution – down to atoms!” This insight allows the team to be innovative. Sandy says, “In my group, we try to go back to first principles to see if there are untrodden paths.” By keeping their minds open, Sandy and his team might just discover a metal that could change everything.

HOW ARE SUPERALLOYS LIKE CAKE?

A cake is light, spongy and holds its shape – but is that anything like the physical properties of the flour, eggs or butter that it is made of? When elements are mixed in the right way, some remarkable chemistry can create a product that is completely different to any of the ingredients. The same is true for alloys, which are mixtures of metal elements.

Superalloys are alloys that are still strong even when they are close to their melting temperature. Sandy and his team have already created and tested some impressive tungsten-based superalloys. In one example, they fused tungsten with titanium and iron by heating the mixture to 1,250 °C for 100 hours. The resulting material – even when heated to 1,000 °C – was 20 times stronger than concrete!

HOW WILL SANDY'S METALS BE USED?

“Our goal is to construct commercial fusion power plants that can run for at least 20 years,” explains Sandy. “This means our materials must withstand the intense stress and energy from the fusion plasma for decades.” There are still lots of experiments to do, therefore, to find the perfect material and prove it is robust enough for the job. Sandy’s team has access to particle accelerators, which can simulate the high levels of radiation his metals will experience in a fusion reactor.

PATHWAY FROM SCHOOL TO EXPERIMENTAL METALLURGY

- Metallurgists often study for a degree in materials science, but you can also readily enter the field from a background in physics, chemistry or engineering.
- A good level of maths is required across many science and engineering degrees. Chemistry, physics, biology, computer science and design technology are all useful too.
- To work in research and development, it is useful to a master’s degree and, possibly, also a PhD.

ABOUT EXPERIMENTAL METALLURGY

With its roots in blacksmithing and steel production, metallurgy is the study of all things metal. This includes not only the 94 metallic elements in the periodic table, but also the compounds they form and the alloys that can be produced by mixing them together. Metallurgists create, examine and test these materials so they can be used for construction and technology. Their work is all around us in bridges, engines and electronics; over our heads in spacecraft; and behind the scenes in many production lines and power plants.

WHAT HAPPENS IN AN EXPERIMENTAL METALLURGY LAB?

Much of the work in metallurgy happens in the lab, where there are four main stages:

1. A design for a new alloy is suggested, along with a recipe for how to make it.
2. The material can then be produced by a combination of melting, mixing and baking.
3. The results are examined using electron microscopes to find out exactly what has been produced.
4. The material is tested for whatever properties are important, such as strength, weight, durability or heat resistance.

Sandy describes his job as “curiosity driven research”. It is exciting to think of something nobody has tried before, persuade other people it is worth researching and then find out if it really works. Science always comes with the risk that not everything will work, but “exploration into the unknown, with the possibility to open up new technologies” is what drives Sandy and his team.

DO EXPERIMENTAL METALLURGISTS WORK IN RESEARCH OR INDUSTRY?

Both! Creating a new material is a process of research and development, and while universities do lots of research, it tends to be companies who develop the results into

a final product. It is important, therefore, for experimental metallurgists – wherever they work – to understand both parts of the process. For example, Sandy’s research group often experiments with new ideas that are a long way from commercialisation, but all their work is linked to an industrial partner so the ideas can make it towards real-world applications.

WHAT OPPORTUNITIES ARE THERE FOR FUTURE METALLURGISTS?

As technology progresses, every generation of metallurgists gets a better understanding of how materials work, so the future undoubtedly holds new discoveries. There are plenty of challenges that metallurgists will need to solve in the coming decades. For example: can we find a way to sustainably source metals for electric vehicle batteries? How can we recycle the metals in the ever-growing amount of electronic waste? Could better metals help us transition to renewable energy as well as nuclear power?

DESIGN OF NEW ALLOYS

DESIGN STRATEGY

MELTING & PROCESSING

Arc-melting, hot & cold rolling, thermal treatments

CHARACTERISATION

Electron microscopy (SEM, EDS, EBSD, TEM, STEM), Calorimetry

PROPERTIES

Mechanical testing and irradiation

HOW DID SANDY BECOME AN EXPERIMENTAL METALLURGIST?

“From an early age, I was LEGO obsessed, and then I was into models and computers. If I were a kid now, I am sure I would be playing with Raspberry Pi & Arduino – these are great ways to get into coding and engineering. Outdoor sports have been another long-term interest, from mountaineering to skiing, cycling and running.

As a youngster, I was inspired by a family friend who was a flight engineer, maintaining aeroplanes in-flight next to the pilots. I was gutted when I heard the role no longer existed! I then turned my head to architecture, then engineering, then chemistry, until eventually I came across materials science. The blend of engineering, physics and chemistry it uses to reveal the ‘science of materials’ is the perfect fit for me!

I chose to specialise in metallurgy because I liked the connection to large-scale engineering and the hands-on experiments. My interest in aerospace, fusion and nuclear grew after working on jet engines

with Rolls Royce on a summer internship. I now also do work on thermal solar power and hydrogen energy storage – metallurgy has opened up a wide variety of work for me, much of which helps to address the climate emergency.

Curiosity and determination enable me to think creatively, research if an idea is viable, design experiments, get hands-on in the lab, analyse the data and then put the results out into the world. Teamwork is also important, be it helping each other in the lab or meeting with collaborators from other universities and industry partners around the world.

When you enjoy your job, the work-life boundary can become blurred! I want to see my ideas come to fruition, the team is enthusiastic, and we feel part of the societal move to net-zero. That said, I make plenty of opportunities to spend time with friends and family, enjoying sports and travel.”

SANDY'S TOP TIPS

1. Pick a direction to go in and work hard for it, but don't feel you have to be tied to it forever. My career decisions are often guided by keeping my options open. I started in aerospace, moved to nuclear fusion and now also do hydrogen and solar energy!
2. Some of the most useful internships/work experience I did were the ones that told me I didn't like a particular area.
3. Talking to people at different career stages about their career route was a great way to work out what I wanted to do myself.

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MEET THE TEAM



MANGALISO BROWN

Laboratory and Research Technician

Designing, developing, assembling and maintaining laboratory equipment. Implementing and monitoring the compliance of health and safety.

“There are always opportunities to learn and try new things in metallurgy and materials. My day can include anything from analysing samples to trouble shooting why an experiment isn’t going to plan and anything in-between. I’m always learning and looking for new challenges.”

TOP TIP: Go through life enjoying every moment; learn from the lows and embrace the highs.



VINCENT GAGNEUR

PhD Researcher

Studying the micromechanics of novel titanium alloys for aerospace gas turbines.

“I like the diversity of the experimental techniques that can be used, as well as the freedom to shift from one to another. This allows me to be creative in the lab. Diving into theoretical literature can be challenging, but it’s an important part of the work. I started coding automated data analysis software codes out of laziness! It resulted in helping a few co-workers and opening a route for more research.”

TOP TIP: Surround yourself with people you trust – they’ll push you towards things you care about.



JÓHAN MAGNUSSEN

PhD Researcher

Exploring alloys for next-generation nuclear power plants, with the potential to improve the efficiency of electric power generation for the future.

“The science of metallurgy has direct connections to real world problems. In the case of zirconium alloys that I work on, an improvement in alloy design could improve nuclear power plant efficiency and/or lifetime, both of great worth to society. The field of alloy design draws on most aspects of metallurgy, so it takes a greater breadth of knowledge than some other fields. The challenge lies in being able to collate results and maintain a balance of properties.”

TOP TIP: Enjoy your work – you don’t need to be in a hurry to reach a specific goal.



SOPHIA VON TIEDEMANN

PhD Researcher

Developing new iron-based superalloys for very high temperatures and nuclear applications. Researching the microstructure of different alloy systems and how proton irradiation affects their properties.

“I find it fascinating to see how performing certain treatments on a material changes the microstructure and, hence, its properties. For example, shooting protons at a material changes its structure through the displacement of atoms, which we can see through electron microscopy and measure physically through analysing hardness. It’s motivating to know that this research plays a vital role in establishing low-carbon energy solutions for the future.”

TOP TIP: Learn to take things as they come.



DR TIANHONG GU

Research Fellow

Analysing superalloys and developing an understanding of microstructure and advanced characterisation techniques, applied to aerospace and nuclear energy. Teaching and supervising MSc and PhD students.

“Designing the undergraduate and postgraduate projects for students, as well as designing and setting up new experiments can be challenging, but it is also very rewarding, and I enjoy the friendly scientific environment and the variety my role offers. I have been motivated to become an independent scientist in the field and want to encourage more female students to join the metallurgy and materials community. Publishing my research in leading international peer-reviewed journals and supervising successful students are proud moments for me.”

TOP TIP: Trust yourself!



DR PEDRO A. FERREIRÓS

Research Fellow

Designing and developing new alloys for turbines and nuclear power reactor applications.

“The beauty of being a scientist is that the more one discovers, the more questions are generated, and this never-ending desire for knowledge gives us surprising results. Our work involves teamwork that is constantly enriched by young students and guiding them is the key to generating knowledge together. Our experiments using cutting-edge technology allow us to study from nanometric scales, how atoms are periodically arranged and what defects are generated in these arrangements, to finally define the mechanical properties of the alloys.”

Scan this QR code to visit the team’s website:



FROM FIELD TO LAB: THE CHANGING NATURE OF ARCHAEOLOGY

AS TECHNIQUES IMPROVE, ARCHAEOLOGY IS BECOMING AN EVER-MORE SOPHISTICATED PROCESS. ALTHOUGH SHOVELS REMAIN USEFUL, DIG SITES NOW UTILISE DRONES AND CLEVER IMAGING TECHNIQUES, WHILE BACK AT THE LAB, ANALYTICAL CHEMISTS USE THE LATEST NON-DESTRUCTIVE METHODS TO ANALYSE ARTEFACTS AT THE MOLECULAR LEVEL. ON THE USA'S EAST COAST, A COLLABORATION BETWEEN ST. MARY'S COLLEGE OF MARYLAND (SMCM) AND THE MARYLAND ARCHAEOLOGICAL CONSERVATION LAB (MAC LAB) HELP BRING THESE STRANDS TOGETHER

Archaeologist Dr Liza Gijanto and analytical chemist Dr Randolph (Randy) K. Larsen lead the Archaeological Investigations of Colonial Maryland project, which brings SMCM and MAC Lab together with Jefferson Patterson Park and Museum to provide undergraduates with wide-ranging experiences that can help inspire and define their archaeological careers.

A UNIQUE HISTORY

Halfway down North America's east coast, not far from Washington D.C., Maryland is a state defined by its history and its geography. "Maryland was an area of early colonial experimentation for the British," says Liza. "Some of the earliest plantations and towns were founded here. In these spaces you had Indigenous communities, European settlers, indentured servants, and enslaved Africans all engaged in a changing socio-economic landscape." Liza believes that archaeology holds many of the answers to how these people navigated changing times, how they interacted, and how their choices influenced the development of Maryland's modern society.

The project focuses on West Ashcom, a former homestead in southern Maryland once dominated by an impressive manor house and the various inhabitants that such a place housed. "As I've been working at West Ashcom alongside my students, I've come to realise that the site represents various periods of socio-economic history," says Liza.

DIGGING FOR ANSWERS

The project provides an introduction for

undergraduate students into the practical world of archaeology. "Students are engaged in all phases of archaeological excavation," says Liza. "This begins with surface surveys and shovel test pits, but our focus has been on full excavation of specific areas." Liza's team uses drones to take aerial surveys of the fields where they work to look for tell-tale features of the land that suggest something is hiding underneath.

The team has made some interesting discoveries. "We have found a lot of tableware from the 17th and 18th centuries, suggesting that despite being inland, people had access to materials from Europe," says Liza. "We also found a cannonball from the war of 1812. Perhaps the most significant find, however, was a bottle seal inscribed with the name of Martha Dansey, only the second found in the area made for a woman."

BACK IN THE LAB

Initial artefact processing involves careful washing, sorting and labelling. Once inventories are generated, Randy steps in to supervise the analysis of samples in more scientific detail. "Students from a variety of academic backgrounds conduct experiments on the artefacts collected, using techniques such as thermal analysis and several different types of spectroscopy," he says.

Thermal analysis involves recording how a sample responds to temperature. Spectroscopy techniques measure how samples respond to different sorts of electromagnetic radiation, such as infra-red. By comparing to known

information about a materials' behaviour, the results of these experiments yield insights into the molecular and chemical makeup of the sample.

BROAD UNDERSTANDINGS

As well as building practical skills, the project provides opportunities for students to build working relationships. "Students network among themselves, as well as with staff," says Liza. "We also mentor alumni through a number of local and national archaeological conferences." Randy draws attention to the cross-disciplinarity of the work. "We bring together students from backgrounds in history, anthropology, archaeology, chemistry and museum studies to work collaboratively on the project," he says.

This meshing of disciplines gives students a more holistic perspective on the world of archaeology. "We believe it is important to demonstrate that archaeology is more than just excavation techniques," says project mentor Nichole Doub. "Learning about archaeological conservation, students understand how excavation and curation link to the research and preservation of the data recovered."

The project staff have already seen the fruits of their labours in the professional development of their students. "My goal has been to train and prepare students for careers in archaeology and museums," says Liza. "It's immensely rewarding to see these students enter professional positions and mentor younger students themselves."

ABOUT ARCHAEOLOGY

Archaeology involves the careful excavation, study and conservation of artefacts to learn more about human history and prehistory.

Liza explains, “There is a push for more emphasis on collections. Students should be prepared to care for and utilise existing collections and try to limit excavation. While excavation remains important, we now have more non-invasive ways to preserve, investigate and manage sites.”

To some extent, what subjects you should take depends on the time period you’re interested in. For more modern history, history and geography are important, while further towards prehistory, there may be more focus on anthropology and geology.”

- The Society for Historical Archaeology

(www.sha.org), Society of American Archaeology (www.saa.org), and the World Archaeological Congress (www.worldarch.org) are good places to start exploring this field.

- St. Mary’s College of Maryland (www.smcm.edu/anthropology) offers regular public lectures, as well as open dig days for anyone interested in archaeology and volunteer opportunities in the lab. It also offers internships or opportunities for its students to be hired as field or lab technicians.

LIZA’S TOP TIP

Take your time. Make sure you get as much practical experience as possible in the field and lab before you reach graduate school.



DR LIZA GIJANTO

Associate Professor of Anthropology
St. Mary’s College of Maryland, USA

FIELD OF RESEARCH

Archaeology

JOINT RESEARCH PROJECT

Running the Investigations of Colonial Maryland undergraduate programme

FUNDERS

US National Science Foundation (NSF), The Cremona Foundation

ABOUT ANALYTICAL CHEMISTRY

Analytical chemistry involves identifying the substances within a sample using often-sophisticated chemical techniques. For archaeological artefacts, these techniques can help identify a sample’s age, place of origin and other characteristics.

Randy explains, “My high school chemistry teacher made chemistry make sense to me. I grew up in an era when environmental activists were protesting against polluting factories. I believed that by learning the science, I could help prevent this pollution from inside the industry. This led me to studying chemical engineering, before specialising in environmental chemistry.

My experiences in graduate school led to an academic position as an analytical chemist. The skills I was using to measure traces of chemicals in the environment are very similar to those needed to analyse the chemistry of archaeological artefacts.

Archaeometry – the use of scientific methods and technologies within

archaeology – is a growing area that needs highly skilled chemists. Finding non-destructive testing methods for important artefacts helps us learn more about humanity’s past, while preserving cultural heritage for future generations.

I recommend taking as many science and mathematics courses as you can. At college or university, I suggest majoring in chemistry or a related subject such as chemical engineering, biochemistry, or material science.”

- The American Chemical Society (www.acs.org/content/acs/en.html) and the Royal Society of Chemistry (www.rsc.org) are two professional organisations with great websites for prospective students.

RANDY’S TOP TIP

Make your own path. Take courses that challenge you and don’t be afraid to try something new. It is only through trying new things that you can find out what you enjoy the most.



DR RANDOLPH K. LARSEN

Professor of Chemistry
St. Mary’s College of Maryland, USA

FIELD OF RESEARCH

Analytical Chemistry

JOINT RESEARCH PROJECT

Running the Investigations of Colonial Maryland undergraduate programme

FUNDERS

NSF, The Cremona Foundation

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MEET SCOTT



SCOTT STRICKLAND, Deputy Director of the Maryland Archaeological Conservation Laboratory and an Adjunct Instructor of Geographic Information Systems (GIS) at St. Mary's College of Maryland

Specialisms: spatial patterning and modelling, colonial records research and studying the history of Anglo-Native interaction in 17th century Chesapeake.

“A typical day consists of going through a GIS-related concept and demonstrating several examples of it used in an archaeological context. GIS is a type of database focusing on location-based data, often visualised using maps. Following an introduction, students are then given sample datasets and instructed how to apply those concepts on their own.

GIS is used most often in archaeology to

digitise and reference multiple datasets using real-world coordinates. This allows plans of excavations to be overlaid with other spatial data, such as soil composition, topography and other environmental data. Additionally, field data can be mapped to create distributions of artefact types.

In this programme, I see students go from having no background in GIS and very basic spatial knowledge to having a good grasp of how to read and interpret complex spatial data and produce high-quality map graphics.

Meeting dedicated students who ask insightful questions is great. This allows me to explore other avenues and tools in GIS that I might not use on a more daily basis.

Before I was an archaeologist, I was a land surveyor. I've always had a deep interest in

maps. I used my interests and experience to carve myself a spot within this niche area. I went to graduate school specifically to learn GIS applications in archaeology.

One discovery I made could be classified as a eureka moment. In the 17th century, major Native towns were typically located on the northern bank of the Rappahannock River. For decades, this phenomenon has been explained as politically motivated, but an archaeology sensitivity model I developed found that environmental reasons were more significant.”

SCOTT'S TOP TIP

Find something you like and run with it, even if it's a niche interest. Find a graduate programme that best suits what you want to do.

MEET NICHOLE



NICHOLE DOUB, Head Conservator, MAC Lab

Specialisms: archaeometallurgy, East Mediterranean/Eastern European archaeology, and historic ships.

“As an archaeological conservator, I help students to understand how the choices made in the planning, excavation and curatorial stages can impact the research and preservation of the data recovered. I give students the opportunity to sample the methods and techniques that conservators use in the treatment of artefacts.

I was pursuing a traditional education in archaeology and looking for a graduate programme to continue my studies when I met a conservator while on an excavation.

Coincidentally, I was also studying chemistry (because my parents didn't have confidence in a career in archaeology) and it seemed natural to combine the two disciplines and pursue a specialisation in archaeological conservation.

Archaeology can be very unpredictable. It is difficult to determine from the outset what the state of preservation may be and exactly what may be recovered. This can be challenging when in the planning phases and we have to rely on research and experience, but it is also enjoyable because the work is rarely repetitive or dull. You also work with a wide variety of colleagues in different specialisations who all share the same curiosity.

Fostering an understanding of the role conservation plays in the archaeological

process is very important to me. Early exposure normalises the multidisciplinary nature of the field. Should any of these students go on to pursue a career in archaeology, they will be better able to communicate and collaborate with their conservation colleagues and be better stewards of our archaeological heritage.”

NICHOLE'S TOP TIP

Formal education will only take you so far – pursue opportunities outside the classroom to acquire new experiences and skill sets. This is enriching and helps when applying for jobs and other opportunities.



MEET ISAAC



DR ISAAC SHEARN, Drone and Photogrammetry Instructor for the project

Specialisms: the archaeology and ethnohistory of the Caribbean and South America, developing inclusive and participatory methods for public archaeology.

“A typical day in the field will include working with a group of students to plan and execute a flight. We decide where we are going to capture imagery, plan a flightpath, and then watch as the drone automatically executes the flightpath. Later, in the lab, a lot more time is required to process and analyse that imagery and integrate it into a working topographic model of the landscape.

I started using aerial imagery and photogrammetry to accomplish a mapping project in Guyana that my graduate advisor

had started back in 2011. I presented the results of that research at a conference, and faculty from St. Mary’s were in attendance. They were intrigued about the technique and approached me to get involved in their project.

Using drones and photogrammetry allows us to produce maps and images with extremely high accuracy and precision, at a fraction of the cost that other comparable techniques such as LIDAR would require. It also allows us to be more flexible in choosing what and where to produce maps.

Students with the patience and interest to get over initial learning and troubleshooting hurdles are often overjoyed at the power of the technique and the potential for future applications. It is always rewarding for me to expose students to new methods and instruct

them in techniques that can be at their disposal.

The first time I tried to create a 3D map from aerial imagery was using from a camera mounted on a kite rather than a drone. I was in the middle of Guyana, had been trying to get it to work for days and had to point fans at the laptop to keep it from overheating because the software can be very intensive! When we first saw the 3D map of the site we were working on, we jumped for joy.”

ISAAC’S TOP TIP
Any meaningful career takes a tremendous amount of perseverance and patience. Make sure you follow the path that will make you happy, and don’t do anything just because others suggest you should.

MEET BECKY



REBECCA MOREHOUSE, Curator of State Collections, MAC Lab

“A typical day as a curator can include everything from responding to research requests, rehousing artefact collections, accepting and recording new collections, processing artefacts for loans to borrowing institutions, or basic housekeeping in the collections storage area.

I worked with my first archaeological collection as an undergraduate and I knew then that I wanted to pursue a career in archaeological collections management. I went on to get a master’s in anthropology and museum studies, which helped me get my first position at the MAC Lab.

I specialised in curating because I enjoyed the lab side of archaeology much more than the field work. I get great satisfaction from rehousing old archaeological collections and making them accessible to researchers and the public.

The challenges of curation include the general lack of resources available to support long-term curation. The rewards include seeing a collection that you have rehabilitated be used by researchers or placed on exhibit for the public.

The most important thing for students of curation to learn is the importance of good organisational skills and attention to detail. Students learn this through lectures on the various curatorial tasks, as well as through hands-on work with collections. For me, the opportunity

to help train a new generation of curators and collections managers is very rewarding.

The eureka moment in my own career was realising there’s more to curation and collections management than just preserving and protecting the collections. The MAC Lab’s collections are held in public trust and belong to Maryland’s citizens. Making them accessible for research, education and exhibitions is equally important.”

BECKY’S TOP TIP
Get as much experience as possible early in your training. Internships, volunteering and part-time work all provide experience and make you a better candidate for graduate programmes and your eventual career.

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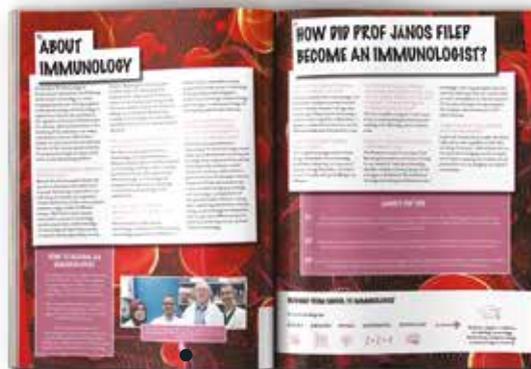


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