

YOU CAN BE WHAT YOU SEE

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SHROUK EL-ATTAR:
AN LGBTQ+ REFUGEE, BELLY
DANCER AND IET YOUNG
WOMAN ENGINEER OF THE YEAR

ALSO IN THIS ISSUE

STEM ALLIANCE

THE EU INITIATIVE BRINGING INDUSTRIES,
MINISTRIES OF EDUCATION AND EDUCATION
STAKEHOLDERS TOGETHER

KREESA SAHA

THE TEENAGER
INVESTIGATING PLASTIC-
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YOU CAN BE WHAT YOU SEE

Positive role models are vital. As humans, we instinctively learn in a social way, meaning we learn best when we observe the behaviours of others. For children, role models will be parents and family members but, as they grow older, teachers, friends, peers, people in their local communities and celebrities become increasingly influential – and the wider their circle of influence, the more likely they'll see themselves reflected in role models who may be BIPOC, female, LGBTQ+ or people with a disability.

"You can't be what you can't see," said Marian Wright Edelman, Founder and President Emerita of the Children's Defense Fund, in the 2011 Sundance documentary *Miss Representation*. The film exposed the mainstream media's contribution to the underrepresentation of women in positions of power in the US. Since its launch ten years ago, the phrase 'You can't be what you can't see' has become a familiar adage – and with good reason. We are increasingly aware of the diverse range of people we have not been given the chance to see – people

who, historically, have not been given a platform to develop and celebrate their talents.

Shrouk El-Attar is an LGBTQ+ refugee, belly dancer and one of the UK's top six young women engineers. As a child, Shrouk did not know any engineers but a science teacher at primary school started Shrouk on her journey to a career in engineering. "Growing up around other people who didn't feel marginalised or had role models already for them, I could see the difference and how powerful that was for them," she says (p 4).

It is with this knowledge that we are thrilled to feature such a variety of researchers in this latest issue of *Futurum*. From a computer scientist using AI for inclusion and social good (p 70) to an anthropologist advocating the need for Indigenous Knowledge in schools and universities (p 12), our researchers are passionate about sharing their work with you, so that students all over the world can be what they see.

KAREN LINDSAY

Director and Editor-in-Chief

ERICA MORGAN

Assistant Editor

ISLA SIMMONS

Editorial Assistant

BRETT LANGENBERG

Director

CHRIS DOWELL

Project Manager

T: +44 117 9099150

E: info@futurumcareers.com

W: www.futurumcareers.com

OUR WRITERS

Jacob Ashton, MA

Rebecca Ingle, PhD

Sam Jarman, MSc

Paul Redmond, MA

Alex Reis, PhD

Isla Simmons, PhD

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OUR GRAPHIC DESIGNER

Claire Leach, BA (Hons)

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CHECK OUT OUR CAREER POWERPOINTS ONLINE ...

Our PowerPoints summarise our articles and include additional 'Talking Points', making them a fantastic classroom resource:

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AND ANIMATIONS!

As part of our free package of education resources, we have started introducing animations. For example:

There is an animation, downloadable script and PowerPoint for Dr Catherine Brissette's article on Lyme disease (p 48): futurumcareers.com/understanding-the-mechanisms-behind-lyme-disease

Animations (and PowerPoints) for Dr Eva Heims (p 54), Dr Alita Nandi and Nicole James (p 58), and Dr Susan Fitzner (p 84) will soon be available.

CONTENTS

RESEARCH ARTICLES

- 8 WHAT IF EXPERIENTIAL LEARNING CAN MAKE STEM MORE ACCESSIBLE FOR STUDENTS OF COLOUR? DR CORLISS THOMPSON
- 12 WHAT IF INDIGENOUS SCIENCE WERE PART OF THE SCIENCE CURRICULUM? DR DARREN RANCO
- 16 OBSERVING THE NEED TO FOSTER INCLUSION AND EMBRACE DIVERSITY DR BRICE ORANGE AND DR DAVID MORRIS
- 20 SEARCHING THE SKIES DR BRAD NEWTON BARLOW
- 24 HOW WERE THE CHEMICAL ELEMENTS BORN? DR MARIA LUGARO
- 28 THE EXTRAORDINARY POTENTIAL OF NANOSCIENCE (FROM A RESEARCHER WITH EXTRAORDINARY POTENTIAL) YASHASWI NALAWADE
- 32 HOW CAN RADIOACTIVE ELEMENTS HELP US? DR DAVIDE AUDISIO
- 36 WHY DO SOME CHEMICAL REACTIONS OSCILLATE? PROF IRVING EPSTEIN
- 40 THE MOLECULES BEHIND PLANT GROWTH DR ALEXANDER JONES
- 44 BUILDING BONES USING STEM CELLS AND GENE THERAPY DR PASCALE V. GUILLOT
- 48 UNDERSTANDING THE MECHANISMS BEHIND LYME DISEASE DR CATHERINE BRISSETTE
- 54 DO INDUSTRIES INFLUENCE GOVERNMENT REGULATORY AGENCIES? DR EVA HEIMS
- 58 HOW ONE MASSIVE STUDY IS UNCOVERING THE SECRETS OF UK SOCIETY DR ALITA NANDI AND NICOLE D. JAMES
- 62 DID YOU THIS READ RIGHT? DR JONATHAN GRAINGER
- 66 SOLVING THE TOWER OF HANOI PROF DAN ROMIK
- 70 USING AI AND COMPUTER SCIENCE AS A FORCE FOR SOCIAL GOOD PROF ZHIGANG ZHU
- 74 USING COMPUTER SCIENCE TO ASSIST IN CREATING AN ULTRA-CLEAN SCIENTIFIC LAB ENVIRONMENT PROF KLARA NAHRSTEDT
- 80 THE OCEAN'S STORAGE SYSTEM: HOW PLANKTON INFLUENCES CLIMATE CHANGE PROF KATSUMI MATSUMOTO
- 84 HOW DOES CLIMATE CHANGE IMPACT AQUACULTURE? DR SUSAN FITZER
- 88 SOLVING A BIOMECHANICAL MYSTERY: HOW JELLYFISH SWIM AND FEED DR SEAN COLIN
- 92 LOOKING TO THE LIGHT: ASSESSING THE PATH TO SPECIES RECOVERY DR MOLLY GRACE
- 96 INQUIRY AND EXPLORATION – ENABLING STUDENTS TO USE LARGE DATASETS DR TANYA JOSEK





INTERVIEWS

- 4 **SHROUK EL-ATTAR**
IET YOUNG WOMAN ENGINEER OF THE YEAR, LGBTQ+ REFUGEE
AND BELLY DANCER

 - 6 **PARIDHI LATAWA**
FOUNDER, SparkED

 - 52 **BJÖRN BACHMANN**
MANAGER, STEM ALLIANCE

 - 78 **KREESHA SAHA**
16-YEAR OLD STUDENT WITH A SCIENTIFIC PAPER UNDER REVIEW
-



SHROUK EL-ATTAR p 4



PARIDHI LATAWA p 6



BJÖRN BACHMANN p 52



KREESHA SAHA p 78

"WE HAVE TO DREAM BIG. IF WE DON'T DREAM BIG, WHY DREAM AT ALL?"

SHROUK EL-ATTAR HAD ALWAYS WANTED TO BE AN ENGINEER – EVER SINCE SHE DISCOVERED THAT LITTLE PEOPLE DID NOT LIVE INSIDE THE TELEVISION. BUT HOW DO YOU BECOME AN ENGINEER WHEN THERE ARE NO ROLE MODELS AROUND YOU – NO ENGINEERS WHO LOOK LIKE YOU OR COME FROM THE SAME BACKGROUND AS YOU? DETERMINED TO BECOME HER OWN ROLE MODEL, SHROUK – AN LGBTQ+ REFUGEE AND BELLY DANCER – HAS BROKEN THROUGH NUMEROUS CEILINGS TO BECOME RECOGNISED AS ONE OF THE TOP SIX YOUNG WOMEN ENGINEERS IN THE UK



How does a television work? In fact, how do any of the modern technologies we use to listen to music, talk to each other, like each other's photos, stream box sets, work? The answer lies in electronics, but for Shrouk El-Attar, a young girl growing up in Egypt, it was magic. One of Shrouk's earliest memories was learning that the people talking, singing, dancing and acting on her television did not live inside it. To

Shrouk, electronics was magic and she wanted to create that magic.

With no understanding of what an engineer can do, and no one around her working in this field, Shrouk did not know she could invent her own electronic devices and become an engineer. "Growing up, I didn't really feel like I had a role model that represented me as a child that I could look up to and say: 'Yes that's the person I want to be when I'm older'," says Shrouk. "So, I felt I had to be my own role model."

And what a role model Shrouk has become. In May 2018, the BBC listed Shrouk, aged 25 at the time, as one of the 100 most inspirational and influential women in the world. In the same year, the United Nations Refugee Agency named her The Young Woman of the Year. In 2021, the Institution of Engineering and Technology (IET) awarded Shrouk the Women's Engineering Society prize and IET Young Woman Engineer of the Year, an accolade she also won in 2020. The question is, how did Shrouk get here? And how can you follow in her footsteps? Shrouk faced many barriers, but she never gave up on her dream to become an engineer.

BECOMING AN ENGINEER WHEN YOU DO NOT KNOW WHAT AN ENGINEER CAN DO

A poll conducted by the Royal Academy of Engineers last year found that 95% of the teenagers surveyed were unaware that engineering jobs exist in the arts, fashion, beauty and hospitality. Indeed, there are many misconceptions about what engineering really is.

It was a science teacher at primary school that first led Shrouk on a rewarding path into engineering. "My science teacher told me that a real scientist always asks why. How are there people on my TV? Why can I breathe? Why is there a voice at the end of the telephone line? How does this all work? That made me more curious. I wanted to find out how everything works on a basic level, at the lowest level possible."

Now, as an electronics engineer, Shrouk has been involved in many diverse projects. She has built a machine that uses electron spin resonance to detect cancer; she has developed smart breast pumps for breastfeeding mums, which are silent and more comfortable to wear; she has built a car and raced it; she has designed robots; and she recently worked as a volunteer for OpenVent, designing emergency ventilators for use in developing countries and the US during the current coronavirus pandemic.

"I feel lucky that by being an engineer I'm able to help in a way that maybe other people are not able to," says Shrouk. "I really think that by being an engineer, I can do whatever I want. It's so creative and it makes me happy. I feel like being an engineer is my superpower!"

BECOMING AN ENGINEER WHEN YOU ARE AN ASYLUM SEEKER AND UNABLE TO ACCESS HIGHER EDUCATION

"I don't do things to upset society. The things I love upset society." Shrouk was 15 when she was granted refugee status because of her sexuality. Shrouk is queer but in her native Egypt, LGBTQ+ people face huge challenges that are not experienced by non-LGBTQ+ residents. Indeed, it is considered the responsibility of the state, local community and family to punish those who are LGBTQ+.

As a refugee in the UK, Shrouk was unable to access higher education for the several years it took for her asylum case to be processed. She also faced international tuition fees, which placed yet another barrier to higher education. Shrouk joined Student Action for Refugees (STAR) and led the campaign for asylum seekers to be granted equal access to higher education – now more than 70 universities across the UK allow asylum seekers to study in their institutions.

Eventually, Shrouk was able to study electrical and electronics engineering at Cardiff University in Wales. Now, alongside her work at



Elvie, a FemTech company that designs technologies specifically for women, Shrouk campaigns tirelessly for the rights of refugees and LGBTQ+ people.

BECOMING AN ENGINEER WHEN YOU DO NOT HAVE A ROLE MODEL

“If engineering had been introduced to me as ‘engineering’, I might not have been interested because there is this a very specific idea of what an engineer is, which is not true.” Shrouk did not have a role model when she was growing up, but she sees huge value in being able to see yourself reflected in people who make decisions or are in positions of influence.

“Growing up around other people who didn’t feel marginalised or had role models already for them, I could see the difference and how powerful that was for them,” says Shrouk. “So, I’d love to see more role models who can represent more people like me. It’s just as important for boys and young men to look up to us as their role models.”

Despite being an inspiration to many herself, Shrouk now has a role model: Yewande Akinola, a chartered engineer who specialises in sustainable water supplies and was recognised as IET Young Woman Engineer of the Year in 2012 and awarded an MBE for her services to engineering and diversity in STEM design and innovation in 2020.

“She’s incredible,” says Shrouk. “I remember finding out about Yewande Akinola a few years ago and realising that she’s a principal engineer,

she’s an MBE, she’s presented all these programmes on the Discovery Channel and Channel 4, she’s creative and she’s a dancer like me.”

BECOMING AN ENGINEER WHEN YOU ARE CREATIVE

“I teach English to refugees in Cardiff. I belly dance. I draw and play some music. I campaign for refugees’ rights because asylum seekers don’t have equal access to higher education.” Shrouk is a creative person, but, unfortunately, education systems around the world tend to divide the population into ‘scientists’ and ‘artists’. You are either one or the other – not both. And yet, the sciences and the arts go hand in hand. According to a blog post written in *Scientific American*, “Nobel laureates in the sciences are seventeen times likelier than the average scientist to be a painter, twelve times as likely to be a poet, and four times as likely to be a musician.”

As Shrouk says, “I feel like we are missing out on so much creativity in engineering, and I really just want to know what the world would look like if we told all these creative people that engineering is for them, too. What kind of amazing engineers would we have had by now?”

TO FIND OUT MORE ABOUT SHROUK,
VISIT HER WEBSITE AT:
WWW.SHRO.UK/

HOW TO GIVE UNDERSERVED STUDENTS THE SPARK TO REALISE THEIR DREAMS

PARIDHI LATAWA IS 16 YEARS OLD AND FOUNDER OF SparkED, A STUDENT-LED INITIATIVE THAT AIMS TO 'EMPOWER, EDUCATE AND ENABLE' UNDERSERVED STUDENTS ALL OVER THE WORLD. PARIDHI TELLS US HOW SHE LAUNCHED SUCH AN AMBITIOUS PROJECT WHEN SHE WAS IN TENTH GRADE



Paridhi visits a school in a low-income district in Asia.

TITLE 1 SCHOOLS PROVIDE STUDENTS IN THE US WITH EXTRA INSTRUCTIONAL SUPPORT BEYOND THE REGULAR CLASSROOM TO HELP LOW-ACHIEVING CHILDREN MEET STATE STANDARDS IN CORE ACADEMIC SUBJECTS. HOW AND WHY DID YOU END UP MENTORING AT TITLE 1 ELEMENTARY SCHOOLS?

Inspired by a senior high school student mentor who had worked passionately with low-income communities, I was put into contact with leaders and principals at low-income Title 1 schools when I was in 9th grade. We were invited to lead science experiments and interactive activities, and provide mentorship for science fair projects. At least 40% of students at Title 1 schools come from low-income backgrounds. My involvement meant I experienced first-hand how minimal support from volunteers, beyond classroom learning, can satisfy students' intellectual curiosity and stimulate a lifelong passion for learning.

WHY ARE YOU SO PASSIONATE ABOUT SUPPORTING UNDERSERVED STUDENTS?

When I visited schools in low socio-economic areas in Asia, I found that students from low-income families were keen to attend a community college to become career savvy and find decent jobs to provide financial stability to their families, but they seemed directionless. With numerous

socio-economic factors working against them, these young minds were not being provided the support they need, and yet their desire to learn was incredibly evident. This deep realisation inspired me to share resources that I am fortunate to have with students in need.

Further, with rapid technological advances, it comes as no shock that 85% of the future jobs haven't been invented yet¹. This is why it's vital to connect youth with current leaders to understand the impact of these advances on their career prospects. Unfortunately, educational barriers are still prevalent, as only 25% of first-generation students attend four-year institutions². I feel fulfilled, happy and fortunate to be able to make even a small but meaningful contribution to the lives and careers of underserved students.

- 1) https://www.huffingtonpost.ca/2017/07/14/85-of-jobs-that-will-exist-in-2030-haven-t-been-invented-yet-d_a_23030098/
- 2) <https://pnpi.org/first-generation-students/>

IN YOUR VIEW, WHAT DO UNDERSERVED STUDENTS NEED TO BE ABLE TO ACCESS THE SAME OPPORTUNITIES AS STUDENTS FROM MORE PRIVILEGED BACKGROUNDS?

- Equal opportunities
- Adequate resources to pursue those opportunities
- Mentors, guidance, role models to guide students into those opportunities and towards the resources
- Strong support networks that allow students to take risks, pursue new and different opportunities and explore different career options.

SparkED is unique in its ability to plug the information gap information for underserved youth by offering omnidirectional support and free resources in various convenient forms, and with the help of experienced professionals and mentors from multiple professional and educational fields. When I say 'convenient forms', I mean our speaker series, panels, summits, tutoring and mentoring services, books, and science and experiment kits for elementary students.

WHERE DID THE IDEA FOR SparkED COME FROM AND HOW DID YOU GO ABOUT SETTING IT UP?

Growing up, I was always aware of the disparities that exist in this world, in terms of resources and opportunities for the underserved. In the final year of middle school, when I learned that volunteer support played a crucial role in increasing educational equity and scientific literacy, especially in underserved communities, I decided to pursue this further. What began as simple webinars/events has now turned into a global initiative empowering youth changemakers!

SparkED OFFERS TUTORING, MENTORSHIP PROGRAMMES, WEBINARS, AND MUCH MORE, AND OVER 1,500 STUDENTS HAVE BENEFITED FROM THESE SERVICES. HOW DO YOU KNOW YOU ARE REACHING THE STUDENTS THAT NEED A SUPPORT NETWORK THE MOST?

Testimonials from attendees and encouragement from mentors have shown that we have been successful in attaining our goals. For example, one student wrote: "As someone interested in STEM, this panel helped me feel more confident about what steps to take to apply to colleges." Also, through the generous partnerships and professional support, we have been able to offer resources worth around \$50,000. We're also working on providing grants for kits, books and awards for a STEM summer robotics academy for Title 1 schools in Austin, Texas, and planning training sessions for teachers in a rural school in Asia.

WHICH OF SparkED's MANY ACHIEVEMENTS ARE YOU PROUD OF MOST AND WHY?

I feel very proud to be able to spread the positive impact of SparkED's work through its many partnerships and chapters [local groups within a larger network or organisation]. SparkED is able to build such partnerships due to the value the community sees in the service SparkED is providing. The virtual nature of our events, especially during the pandemic, has helped the spread of our services beyond Texas to 14 US states and 11 countries.

My efforts received a boost when a few volunteers approached me and requested that I help them start chapters in Michigan and Round Rock in the US. One of the chapters focused on tutoring elementary school students impacted by remote schooling during the pandemic.

We're preparing for our annual summer conference in July, which will include workshops, keynotes and webinars on business, STEM and entrepreneurship. Beyond that we're also planning tech-literacy summits for underserved schools and scholarships for motivated, underserved students.

WHAT ARE YOUR HOPES FOR THE FUTURE FOR SparkED?

Moving forward, I hope to continue building an inclusive, educationally literate community that is able to pursue its dreams despite economic hardships or social challenges.

I finish high school in 2022 and plan to go to college, so I'll continue my work with elementary, middle and high schools but will expand SparkED's reach to include college and post-graduate students.

Operationally, I'd like to have separate foci for schools, colleges and the



Paridhi was awarded the Texas Student Hero Award by the Texas Education Agency. © LASA High School

workplace, and offer specialisms i.e. business, science, social science, etc. I'd also like to expand and set up international chapters, especially in developing countries, which link up to chapters that have more resources in developing countries. So far, we've been able to operate with minimal funding. We're now applying for grants and sponsorship so that SparkED can grow and increase its positive impact in local and international communities.

FINALLY, WHAT HAS LIFE TAUGHT YOU SO FAR?

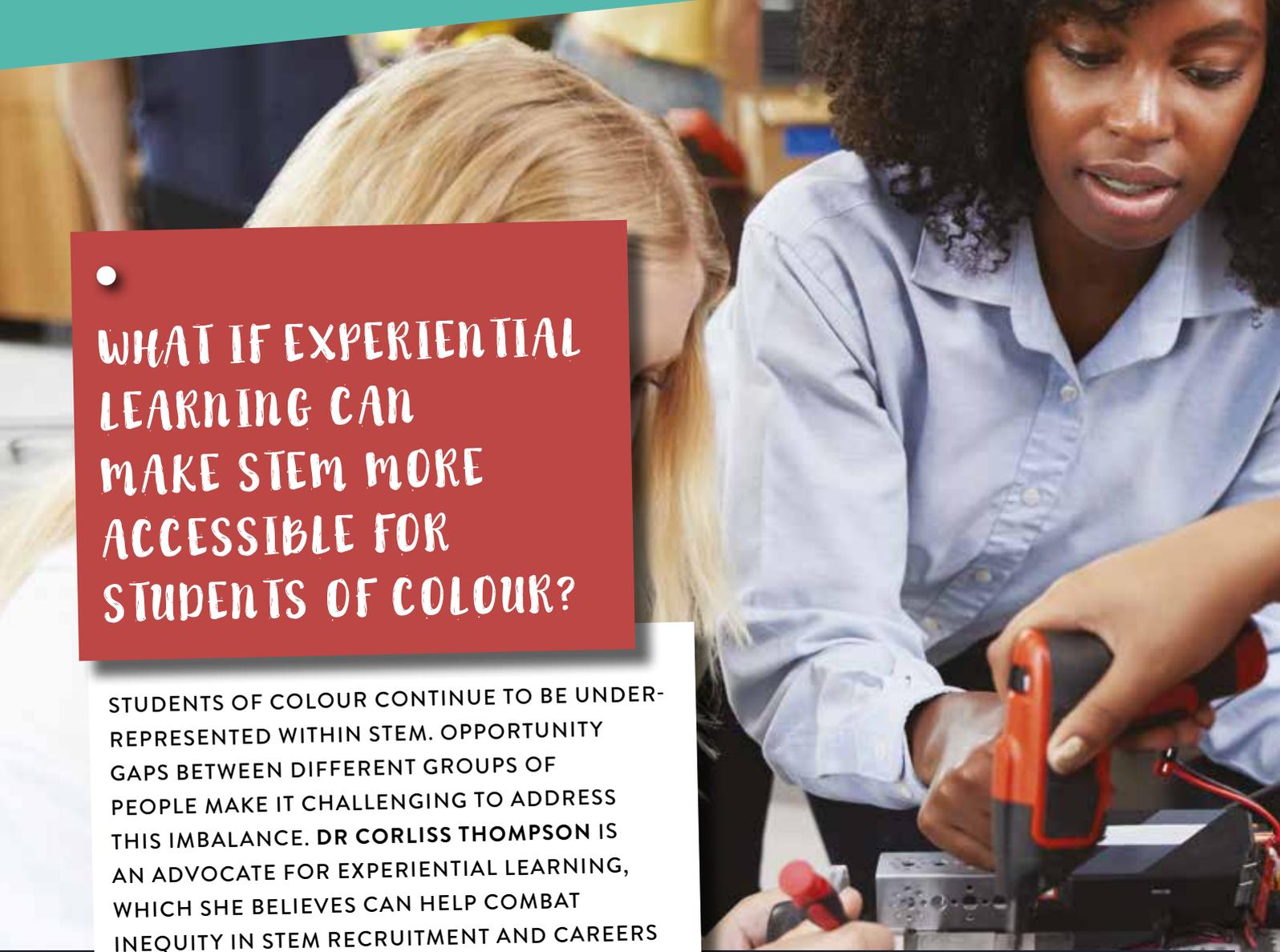
Life has taught me to be grateful for the resources I have, to work hard to make best use of these resources, and to share these resources with others in need. Establishing SparkED has been a tremendous learning experience for me. As the founder of SparkED, my aim was always to promote collaboration through a global team. This has led to lots of challenges but I've managed to turn these challenges into team-building and learning opportunities. SparkED has also given me experience in finance, operations and law.

I've learned that the world is there, ready to help you, if you try.

GET INVOLVED In SparkED's FREE ANNUAL CONFERENCE ON 24 JULY!

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WHAT IF EXPERIENTIAL LEARNING CAN MAKE STEM MORE ACCESSIBLE FOR STUDENTS OF COLOUR?

STUDENTS OF COLOUR CONTINUE TO BE UNDER-REPRESENTED WITHIN STEM. OPPORTUNITY GAPS BETWEEN DIFFERENT GROUPS OF PEOPLE MAKE IT CHALLENGING TO ADDRESS THIS IMBALANCE. DR CORLISS THOMPSON IS AN ADVOCATE FOR EXPERIENTIAL LEARNING, WHICH SHE BELIEVES CAN HELP COMBAT INEQUITY IN STEM RECRUITMENT AND CAREERS

GLOSSARY

ACHIEVEMENT GAP – when one group of students (e.g. grouped by race) significantly outperforms another

EXPERIENTIAL LEARNING – learning through relevant experience and reflecting on this experience

MERITOCRACY – a society where people gain success through merit

MICROAGGRESSIONS – incidents of indirect, subtle or unintentional discrimination

OPPORTUNITY GAP – the recognition that the circumstances of people's lives (e.g. race, wealth) can affect their opportunities

QUALITATIVE DATA – comes in the form of words, descriptions, observations and images such as questionnaires or maps

QUANTITATIVE DATA – comes in the form of numbers i.e. the velocity of a river or amount of litter in a particular area

STEREOTYPE THREAT – when people feel themselves at risk of conforming to stereotypes about their social group, leading to feelings such as discomfort or anxiety

STRUCTURAL RACISM – inherent racism within society, such as discrimination (explicit or implicit) within policies, institutions and education systems

We all know that it is easier to learn about a topic when it feels relevant to us. However, people relate to topics differently, depending on a whole range of factors – such as cultural background, parents' experiences, and expectations for the future. Backed by a growing body of evidence, Dr Corliss Thompson of Northeastern University, USA, believes that this is a key reason why fewer students of

colour enter scientific careers.

“Studies have shown that there can be disconnections with the curriculum for many students, especially students of colour,” says Corliss. “This is partially due to cultural and linguistic disconnections in the classroom, and also because of the ‘education debt’ that contributes to structural racism around the world.”

This ‘education debt’ Corliss mentions is the fact that students of colour, both historically and in the present, typically have fewer educational resources available to them than their white counterparts, as a result of longstanding social, political and economic patterns that reinforce disadvantage. This is a difficult cycle to escape from – but Corliss believes that experiential learning could be part of the solution, if carried out correctly.



DR CORLISS THOMPSON

Associate Teaching Professor, Graduate School of Education, Northeastern University, USA



FIELD OF RESEARCH

STEM Education



RESEARCH PROJECT

Investigating the role of experiential learning in encouraging students of colour to follow careers in STEM



FUNDER

National Science Foundation

EXPERIENTIAL LEARNING

“Experiential learning is a form of acquiring knowledge and building skills through active engagement in immediate, relevant activities, followed by processing and reflection,” says Corliss. “This then leads to continued learning and reflection into the future.” In other words, lessons are tailored to be relevant to the students they are teaching – they draw on students’ past experiences and interests to introduce them to new ideas and concepts.

Corliss goes on to explain: “Connection to previous experiences and relevance to future experiences is a key part of experiential learning. This technique allows learners to connect their interests and understandings to new ideas and skills in a way that fosters development.” Corliss believes this approach is especially important for teachers and students within under-served communities, given the well-documented link between low economic wealth and fewer educational opportunities.

MAKING IT WORK FOR STUDENTS OF COLOUR

“STEM can be seen as a ‘social identity’, that people can subscribe to or not,” says Corliss. “STEM identity is important for under-represented minorities, but historically research has pointed out achievement gaps rather than focusing on students’ strengths.” Corliss wants a move away from this negative outlook and instead concentrate on students’ potential, such as by encouraging under-represented students who have shown an interest in STEM to explore it further in relation to their identity and ability.

With this in mind, Corliss’ research focuses on opportunity gaps rather than achievement gaps. One opportunity gap arises from usually well-meaning colour-blind ideologies – when teachers

teach all students in the same way, irrespective of racial backgrounds. Although probably done with good intentions, this can put students of colour at a disadvantage, given that standardised lessons are more relevant to the experiences of their white peers – around whom the education system was historically built – than themselves.

There are other common opportunity gaps, too. For one, the US supposedly works on a system of meritocracy – in other words, you get out what you put in. When it comes to education, however, this does not always hold true, because students do not start on a level playing field. If you are disadvantaged from the outset, it can be difficult to catch up. When this is coupled with the effects of structural racism – for example, education institutions may expect students of colour to do less well in exams, so spend less effort preparing them for ambitious careers – it can create a vicious cycle that prevents generations of people from seeking high-skilled careers such as in STEM.

LESSONS FOR RESEARCHERS AND TEACHERS

So far, Corliss’ research has focused on qualitative data, with quantitative data soon to come. Nevertheless, her team has already uncovered some key insights. “We know that it is not just hands-on activities that contribute to experiential learning,” says Corliss. “Our study also assessed relationships, the physical environment, and the surrounding culture.” For instance, one type of experiential learning they measured was students experiencing what it is like to be physically present in an engineering firm, building relationships with the engineers and learning the culture of the firm and wider engineering community.

One of the researchers’ principal findings is that a lack of resources can limit opportunities

for experiential learning. For instance, industry partnerships, coordination between scientists and teachers, or training teachers in experiential learning all take time and money to set up. “Districts with fewer resources may be at a disadvantage when it comes to providing experiential learning opportunities for students,” says Corliss. “It becomes more difficult to give students the opportunities to think, solve problems, and gain insight into the relationships and cultures found within STEM professions.”

Corliss’ team also found that experiential learning can even have the potential to perpetuate opportunity gaps in certain scenarios. This shows that while experiential learning can be useful, it needs to recognise and address opportunity gaps as a first step. For instance, it can be difficult for teachers to provide a culturally relevant learning experience to students from another culture, if they themselves have little experience or knowledge of what is relevant to those students’ lives. Corliss believes that recognising that structural inequity exists around race is key to making sure that experiential learning is as effective as possible.

ABOUT STEM CAREERS

Corliss gives her thoughts on why STEM careers should be encouraged for people from all backgrounds.

WHAT IS A STEM MINDSET?

A STEM mindset is a way of thinking characterised by critical thinking skills, growth-orientated mentality, and a willingness to use STEM ideas and skills to address everyday challenges.

WHY ARE STEM CAREERS IMPORTANT?

The United States, along with many other nations, is dependent on a thriving STEM workforce to maintain the health and well-being of its citizens, as well as creating advancements that improve people's lives. The number of STEM-related jobs available is increasing, at a faster rate than the number of students making STEM-related education choices – particularly in areas such as computer science, which are growing the fastest.

WHY ARE PEOPLE OF SOME BACKGROUNDS UNDER-REPRESENTED IN STEM?

There is a shortage of STEM-prepared students in general, but especially for females and some students of colour. There are many suggested reasons why there are fewer women choosing STEM careers, including a shortage of female role models, gender stereotyping, lack of family support and less flexible work environments. When it comes to minorities, factors such as a perceived uninteresting curriculum, microaggressions and stereotype threat are put forward as likely reasons for under-representation, though the exact relationships are not yet fully clear.

HOW HAS EDUCATION CHANGED RECENTLY IN THE US?

US high schools have shifted towards standardised testing and away from comprehension and application of concepts. Due to the pressure to perform well on these tests, teachers are often under the misguided

impression that direct instruction is the best way to prepare students. However, a large body of evidence suggests that traditional classroom settings disengage students and do not promote the skills needed for modern STEM jobs and civic life. The National Research Council found that effective STEM instruction involves students' interests, backgrounds and previous knowledge.

WHAT HELPS PEOPLE CHOOSE STEM CAREERS?

Giving students the support and structures they need throughout their educational career is key. Early exposure to practical, real-life STEM examples, collaborations with local higher education STEM departments, mentorship, and informal STEM learning environments such as camps and after-school programmes can all broaden students' experience of STEM. Outside of the classroom, hands-on STEM activities such as internships and research opportunities can help cement students' interests in STEM careers.

STEM ORGANISATIONS TO LOOK OUT FOR

- The National Action Council for Minorities in Engineering (NACME) provides scholarships and career advice to support Black/African American, Native/American Indian, and Latinx/Hispanic American young women and men taking on STEM careers: <https://www.nacme.org/about-us>
- In the UK, STEM Learning is an organisation committed to furthering STEM education, through training teachers, bringing STEM role models into schools and providing long-term support for schools: <https://www.stem.org.uk>
- Collegexpress has a list of STEM Scholarship Opportunities for Minority Students: <https://www.collegexpress.com/articles-and-advice/financial-aid/blog/stem-scholarship-opportunities-minority-students/>
- This webpage provides a list of diversity initiatives in STEM fields in the US: <https://libguides.mssm.edu/diversity/orgs>
- Black British Professionals in STEM (BBSTEM) campaigns for balance and representation of Black individuals in STEM and runs the Bridge Mentoring Scheme: <https://bbstem.co.uk>

DIVERSITY IN STEM: SOME STATISTICS FROM THE US

- Between 1990 and 2018, STEM employment grew by 79% in the US. Computer jobs increased by 338% in the same period.
- Blacks make up 11% of the US workforce overall but represent 9% of STEM workers, while Hispanics comprise 16% of the US workforce but only 7% of all STEM workers. Representation has improved since 1990 but is not there yet.
- Women comprise 47% of all employed adults, but only make up 14% of engineers, 25% of computer workers, and 39% of physical scientists. Representation is roughly proportionate for the life sciences and maths, and women are over-represented (75%) in healthcare careers.
- STEM workers earn more on average than non-STEM workers of a similar education level.

<https://www.pewresearch.org/social-trends/2018/01/09/diversity-in-the-stem-workforce-varies-widely-across-jobs/>



MEET CORLISS



WHAT DID YOU WANT TO BE WHEN YOU WERE YOUNGER?

As a young child, I wanted to be a meteorologist. I was fascinated by weather and the outdoors, and enjoyed seeing the local meteorologists on TV. I was interested in how they could talk about complex ideas in a way that was useful to people's everyday lives.

DID YOU EXPERIENCE ANY OPPORTUNITY GAPS GROWING UP?

I was raised in a middle-class, suburban household in a predominantly white area, which influenced my personal cultural norms. My parents did make an effort to teach us Black history and gave us opportunities to engage with other African Americans. They also bought us Black dolls, and our house was full of Black art and photography.

HOW DO YOU APPROACH CHALLENGES, BOTH PERSONAL AND PROFESSIONAL?

The ability to learn is a gift. We can each learn what we need to address our challenges, and learning comes in many different shapes and formats. I constantly learn through reading, non-fiction audiobooks and podcasts that cover personal

development, business and leadership. We also need the help of others to further our learning. I often only realise the limitations of my knowledge on a topic when I talk to others about it, and this is an opportunity in itself. Once all this learning has been taken on board, we need a way to process it. I find that journaling or any kind of writing helps me find clarity, along with simply sitting quietly or letting my mind wander while I walk in nature.

DO YOU SEE YOURSELF AS A SUCCESS STORY?

I do, though I don't consider my experience as a unique success. My successes have been built on the shoulders of people in my life who were successes in their own right. My family has a history of further education, even when the institutions were very much dominated by white students. I was therefore expected to go to college and pursue a career, and my family have helped me out financially and emotionally at many different times. On the other hand, even though I haven't frequently experienced overt discrimination, I have experienced structural racism. I have had to find ways of dealing with these challenges to find success.

WHO INSPIRES YOU?

I am inspired by the leaders who make a difference in the world, while also looking after their families, health and well-being. Some of the leaders I count are within my own family. Others I have worked with directly, and others I am inspired by from a distance.

TOP TIP FOR YOUNG PEOPLE OF COLOUR

We all come from different backgrounds and people need different sorts of help to learn – especially social and emotional learning, which is how we become a well-rounded person. Do what is needed to take care of your well-being and ask for help when needed.

TOP TIP FOR TEACHERS

Teachers have a critical role in supporting the learning and well-being of people. To ensure they can do this effectively, self-care must come first.

WHAT IF INDIGENOUS SCIENCE WERE PART OF THE SCIENCE CURRICULUM?

FOR CENTURIES, NATIVE AMERICANS HAVE RELIED ON THEIR KNOWLEDGE ABOUT THE ENVIRONMENT TO SURVIVE. THIS KNOWLEDGE HAS BEEN PASSED DOWN FROM GENERATION TO GENERATION AND MODERN-DAY SCIENCE IS FINALLY STARTING TO REALISE HOW VALUABLE IT CAN BE. HOWEVER, SCIENCE IS NOT A POPULAR CHOICE AMONG NATIVE AMERICAN STUDENTS. TO ATTRACT THESE STUDENTS TO STEM-RELATED COURSES, DR DARREN RANCO, FROM THE UNIVERSITY OF MAINE, USA, HAS DEVELOPED A NEW CURRICULUM WHICH BLENDS CONCEPTS FROM BOTH INDIGENOUS KNOWLEDGE AND WESTERN SCIENCE

TALK LIKE AN ANTHROPOLOGIST

INDIGENOUS PEOPLES – also referred to as Tribal Nations, First Peoples or Native Peoples, these terms describe peoples who are native to a particular place. Typically, the plural ‘peoples’ is used to refer to different groups and tribes, each with their own religion, culture or language

COMMUNITY ELDERS – this is the go-to person within indigenous communities. Elders are respected and consulted due to their experience and knowledge. They can be described as the ‘custodians of knowledge’ or the ‘libraries’ of a community

TRADITIONAL ECOLOGICAL KNOWLEDGE (TEK) – this refers to all knowledge gathered over generations of Indigenous peoples. This knowledge is passed down from one generation to the next through stories and cultural expressions such as arts, crafts and the preparation of traditional foods, for example

KNOWLEDGE KEEPERS – keepers of Indigenous knowledge that has been passed down from generation to generation. Their duty is to preserve this knowledge for their communities and the next generation

ANTHROPOLOGY – the study of human beings and their ancestors, including origin, behaviour and physical, social and cultural development

WESTERN SCIENCE – in this context, Western science refers to knowledge obtained through the application of the scientific method. It starts with an observation, followed by a hypothesis that is tested with experiments

Aspirin is a common painkiller, widely used to reduce aches and pains such as headaches and toothaches, treat colds and flu-like symptoms and bring down a fever. It was first introduced in the West in the late 1800s to early 1900s, at about the same time as medicine cabinets and the concept of keeping medicine at home, but its active ingredient – salicylic acid – was discovered thousands of years earlier in the form of willow bark. Native Americans are known to have chewed the bark or boiled leaves from the willow tree to treat pain and fever.

This is just one example of the many scientific innovations born from ancient knowledge and discoveries made by Indigenous peoples. And yet, despite the recognised value of Indigenous knowledge, there are very few Indigenous

scientists and Native American students often shy away from STEM-related courses at the undergraduate and postgraduate level.

Dr Darren Ranco is an anthropologist based at the University of Maine. He is also a citizen of the Penobscot Nation, a sovereign people in the Wabanaki Confederacy of Tribes. The Penobscot Nation is indigenous to what is now Maritime Canada and the northeastern United States, particularly Maine. Darren is investigating ways to attract more Indigenous students into STEM – a sector that would benefit hugely from the input of Indigenous knowledge.

UNESCO describes Indigenous knowledge, also known as Traditional Ecological Knowledge

(TEK), as, “the understandings, skills and philosophies developed by societies with long histories of interaction with their natural surroundings”. This includes knowledge of plants, animals and natural events, as well as techniques for hunting, fishing or farming. These understandings, skills and philosophies have been passed down over many generations to ensure survival. Given the pressing environmental and societal challenges we all face, blending TEK with Western science seems all the more vital – and encouraging Indigenous students to study STEM subjects is one way to facilitate this.

THE WAY FORWARD

Interestingly, to attract Native American students to STEM-related courses, Darren



DR DARREN RANCO

Associate Professor of Anthropology
Chair of Native American Programs
Coordinator of Native American
Research, Department of Anthropology
University of Maine, USA

FIELD OF RESEARCH

Anthropology and Native
American Studies

RESEARCH PROJECT

The Wabanaki Youth in Science (WaYS)
programme aims to inspire Indigenous
students to follow a STEM-related course.

FUNDERS

National Science Foundation
US Department of Agriculture

advocates a blend of Western science and Indigenous knowledge. Currently, Indigenous students face an academic structure that is heavily based on the Western school system, which is in direct conflict with the social rules and practices of Indigenous communities.

To tackle this issue, Darren and his team created the Wabanaki Youth in Science (WaYS) Program. Set up in 2013, its initial aim was to promote STEM fields and Native American environmental stewardship to middle and high school students. The students go on summer camps, or miniature camps throughout the year, where they are offered various hands-on learning activities, such as hiking, foraging, fire building, ice fishing, archaeology, shelter-building, leadership training and other educational ventures.

Now, WaYS has been extended to support Native American students at the University of Maine. The idea here is to combine Indigenous science and Western science as part of the same undergraduate course. For example, students learn how to identify a plant (Western science), as well as the parts of the plant that are used for medicinal purposes (Indigenous knowledge). In this way, Indigenous students are exposed to their cultural and environmental heritage within the context of modern-day science.

Darren and his team have developed four courses: forest vegetation, forest landscape management and planning, hydrology and Indigenous science. The courses have only run

for two years but, so far, the feedback has been very positive. “We can’t escape Western science and don’t want to,” explains a student who attended one of the courses. “I think that it is really beneficial to understand how [Western science] goes hand in hand with TEK and how the Natives were practising science.”

PASSING KNOWLEDGE ON, THE INDIGENOUS WAY

Darren believes another way to encourage Indigenous students into STEM is to work with Community Elders and Knowledge Keepers from Native American tribes. These experts are ideally placed to become mentors and role models for Indigenous students thinking about a career in science. As such, Community Elders and Knowledge Keepers helped design the curriculum and are co-teaching the courses.

When Indigenous students experience Indigenous teachers, who teach a curriculum framed around Indigenous knowledge and customs, they are more likely to connect with Western science and understand its relevance to them. Similarly, Indigenous mentors and role models can guide students in their life decisions, as well as provide inspiration and support. Indeed, Darren recently received funding by the US Department of Agriculture to create a new mentorship programme called WaYS Ambassadors. This programme involves Native American graduate and undergraduate students helping their peers with research projects and professional development activities at the University of Maine.

BENEFITS FOR ALL STUDENTS

Excitingly, Darren and his team are finding that the benefits of the WaYS project extend well beyond Native American students. Many students have minimal understanding of Indigenous peoples’ culture, history and knowledge. Presentations given by Native American speakers are fascinating and truly eye-opening, offering a more holistic understanding of science. Not only that, but Indigenous experiences are likely to resonate with students from other backgrounds and traditions, many of whom are underrepresented in STEM.

Darren believes that the WaYS programme is a starting point for driving changes within all academic institutions, not just at the University of Maine. “The positive results from this project and research provides the initial mechanism to start turning around the dominant pedagogy in post-secondary education. The two-year study was just the beginning, but it was a strong start to initiate change,” he says.

MORE ABOUT INDIGENOUS KNOWLEDGE

Indigenous knowledge is the accepted term to explain a set of social, physical and spiritual understandings of Indigenous peoples. Also known as Traditional Ecological Knowledge (TEK), Indigenous knowledge combines observations about the local environment with sustainable use of natural resources. Canadian environmentalist Dr Deborah McGregor defines it as, “a system of classification, a set of empirical observations about the local environment, and a system of self-management that governs resource use”.

INDIGENOUS SCIENCE

Indigenous science is the science developed by Indigenous peoples outside accepted scientific research. You can think about it as the process by which Indigenous peoples acquired knowledge of the natural world around them. Some Indigenous peoples are attempting to incorporate scientific knowledge into their practices. Likewise, Western scientists are beginning to take on board aspects of Indigenous knowledge.

BLENDING INDIGENOUS KNOWLEDGE WITH WESTERN SCIENCE

While Western science looks at the world through a detailed and narrow lens, Indigenous knowledge takes a more holistic approach. The willow tree and aspirin are a good example. Not only did Indigenous peoples use the willow tree for its medicinal properties over 5,000 years ago, they also used it to make fishing nets, baskets and fish traps, and much more. Later, in 1828, French pharmacist Henri Leroux isolated salicylic acid from the willow bark to its crystalline form, paving the way for the painkiller that is used in modern medicine today.

“Often, indigenous science traditions include things that are not considered in Western science like the responsibilities and systems of self-management mentioned in Deb McGregor’s definition,” says Darren. “Among these are what Dr Gregory Cajete, a Native American educator, calls the four aspects of being: mind, body, emotion and spirit. Western science only values the mind and sometimes the body, whereas Indigenous science sees all four as elements of knowledge.”

MAKING BASKETS

Another good example is Darren’s basket-

making lesson. He asks his undergraduate students to look for ash trees suitable for making baskets. This activity involves using a combination of Indigenous navigation skills and modern-day location technology. The lesson also introduces the concept of ‘basket-quality’. For Indigenous peoples, the ash tree has to have certain qualities to make it suitable for making baskets. In Western science, this basket-quality knowledge is relevant to forestry science, which considers how some factors – like soil type and climate – can influence tree growth. “Each tradition (Western and TEK) speaks of location and tree development in different, but interrelated ways,” Darren explains.

PLAYING CATCH-UP

In 2018, researchers in Australia discovered that falcons and kites intentionally carry burning sticks to spread fire. The birds do this to force their prey to run from the fire, making the prey easier to catch. While new to Western science, this behaviour was long known to the Indigenous peoples of northern Australia, who also make use of it in their ceremonial practices.

HOW TO BECOME AN ANTHROPOLOGIST

- Anthropology is such a broad subject that there are no strict career paths. You can pursue a career in civil service, conservation or heritage management, to name just a few. Working for charities, museums or teaching are also possible options.
- If you want to find out more, the AnthroGuide, published every year by the American Anthropological Association, is a good place to start. It includes hundreds of academic programmes, as well as information about museums, research organisations and government agencies: <https://guide.americananthro.org/>
- According to the US Bureau of Labour Statistics, an experienced anthropologist earns, on average, \$63,670 per year. Employment for anthropologists is projected to grow 5% from 2019 to 2029, which is faster than average.

PATHWAY FROM SCHOOL TO ANTHROPOLOGY

- To become an anthropologist, you will need a degree or a master’s in anthropology or the social sciences, which typically involve field work and laboratory research. Some positions may require a doctorate.
- If you have an interest in the humanities or geography, then anthropology may be the subject for you. Empathy and a sense of the vastness of the world are hugely beneficial in anthropology.
- You can choose to focus on specific areas of anthropology: biophysical (also known as forensics), sociocultural, linguistical or archaeological anthropology.

DARREN’S TOP TIP

Allow yourself to ask questions about the usefulness of your education and how it is making an impact on you and the world.

HOW DID DARREN BECOME AN ANTHROPOLOGIST?

YOU STUDIED ANTHROPOLOGY AT DARTMOUTH COLLEGE AND HARVARD UNIVERSITY. WHAT SPARKED YOUR INTEREST IN ANTHROPOLOGY?

Very much the question of what it means to be a Penobscot Nation citizen in the (then) 20th century. The questions around identity have always been critical to me. As a Penobscot growing up outside the reservation – which for me was only a few miles away – I felt disconnected in many ways. I think the distance can lead to the kinds of questions that anthropology allows on some level.

WHAT SKILLS OR PERSONAL ATTRIBUTES DO YOU HAVE THAT MAKE

YOU A GOOD ANTHROPOLOGIST?

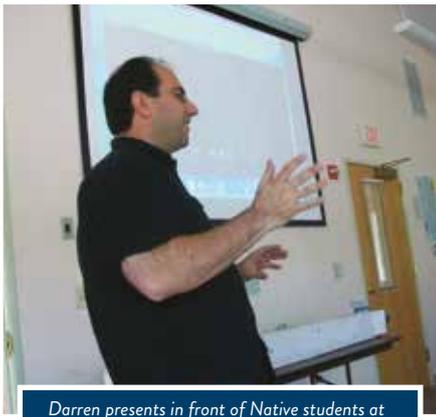
I would say listening is important. My parents taught me to value all people, listen to what they had to share and learn from them. This also involves asking questions from different points of view. Anthropologists still sometimes struggle with asking people they are working with what they would like to know about x, y, or z.

CAN YOU GIVE EXAMPLES OF OTHER ANTHROPOLOGICAL PROJECTS YOU HAVE WORKED ON?

My PhD dissertation project looked at how environmental risks associated with pollution were understood differently between the US

Environmental Protection Agency and the Penobscot Nation.

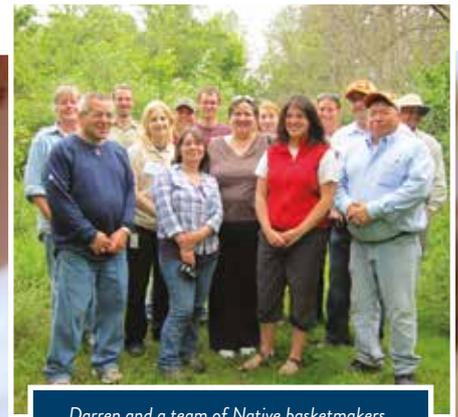
I have also worked on projects related to how Wabanaki basketmakers can react to an invasive species [like the Emerald Ash Borer - see image below] and how their perspectives can centre the response to pests. This was the first project I got involved with when I came back home to Maine in 2009. It showed how impactful research partnerships can be. We were able to establish, and re-establish, partnerships that are impacting the response to the invasive pest to this very day.



Darren presents in front of Native students at the Penobscot Nation. © Penobscot Nation Department of Natural Resources



Darren, Wabanaki basketmakers and harvesters investigate the impacts of the Emerald Ash Borer on ash trees in Michigan – the same trees used in making baskets by Penobscot and other Wabanaki Tribes. © Jennifer Neptune



Darren and a team of Native basketmakers and harvesters meet with US Department of Agriculture scientists to understand the impacts of the Emerald Ash Borer. © Jennifer Neptune



The first graduating class of students from UVI with a Bachelor of Science degree, in physics. Pictured (from left to right) are Dr David Morris, Dr Antonino Cucchiara, Azhar Hussein (Physics B.S. '19), Jonisha Aubain (Physics B.S. '19), Alexander Fortenberry (Physics B.S. '19), Megan Grant (Chemistry B.S., Physics A.S. '19), Dr Jan Staff and Dr David Smith.

OBSERVING THE NEED TO FOSTER INCLUSION AND EMBRACE DIVERSITY

DR BRICE ORANGE AND DR DAVID MORRIS FORM PART OF THE TEAM BASED AT THE ETELMAN OBSERVATORY IN THE US VIRGIN ISLANDS, AN ESTABLISHMENT FOCUSED ON EDUCATING A NEW GENERATION OF STUDENTS IN PHYSICS, ASTRONOMY AND ENGINEERING

So much of scientific understanding is the result of making observations. The invention of the microscope towards the end of the 16th century led to the ability to observe small objects and structures that were invisible to the naked eye. Similarly, the invention of the telescope a few decades later enabled us to view things that were massive, but millions upon millions of miles away from Earth.

Since then, technological developments have led to the creation of near-unimaginably large telescopes which are located at observatories around the world. One of these, the Virgin Islands Robotic Telescope (VIRT), is located at the University of the Virgin Islands' (UVI) Etelman Observatory in the US Virgin Islands, whose main science goal is rapid follow-up of rare and short-lived transients known as gamma-ray bursts. Gamma-ray bursts (or GRB) are some of the most powerful explosions in the Universe and are the only astrophysical event observed, so far, in both optical light and gravitational waves. VIRT is available to students and researchers who want to conduct hands-on projects related to robotic telescope control systems, observations, data processing and management, and data analysis activities.

Dr Brice Orange, Executive Director of Astrophysicist at the Etelman Observatory, works alongside the Director, Dr David Morris, who is also Associate Professor of Physics at UVI. For Brice and David, one of the key tenets of the Etelman Observatory is to educate a new generation of students and provide an aspirational place for young people to learn and work.

Etelman is a key astrophysics research centre and engineering training component in UVI's physics and engineering degree programmes. It is home to the 0.5 metre diameter, visible-light telescope, VIRT, which is the key scientific instrument used in the observatory's astrophysics research. The observatory also serves as the data and programme management centre for the US Virgin Islands Climate Monitor. This programme focuses on collecting and managing a climate database derived from a network of 17 weather stations distributed throughout the islands of St. Thomas, Water Island and St. John. This programme is also being expanded to include another 19 stations that will provide coverage of the island of St. Croix.

The observatory has a range of research workstations dedicated to solar atmospheric physics, high-energy astrophysics and extreme climate variability studies. The grounds host three experimental rain harvest units and are being rejuvenated to support aspects of sustainable small-scale farming. As a regional physical science research and education centre, Etelman certainly has a lot going on!

EVOLUTION AND GROWTH

A team of dedicated staff, student researchers and volunteers has been an essential part of the observatory's growth. Everyone shares a common vision of maximising the potential of the research initiatives to inspire the next generation of STEM scientists.

Indeed, the UVI has seen a dramatic increase in enrolment in physics and maths courses in recent years, which serves as testament to their efforts. "The observatory also serves as a teaching facility where we hold astrophysics lab courses. It is a tremendous education and outreach venue. We hold approximately monthly outreach events that draw 100-200 attendees, many from the K-12 system," explains David. "These activities introduce



students to astrophysics and the broader field of physics and allow UVI faculty to interact with K-12 students and their parents and make them aware of opportunities to pursue physics and other STEM careers at UVI.”

DIVERSITY IN PHYSICS AND ENGINEERING

UVI is an HBCU, that is, a Historically Black College/University and its student population is predominantly of demographic groups who have been historically under-represented in STEM fields. The team is proud that among the physics programme’s first five graduates (from the first two graduating classes in 2019 and 2020), two are women and four are African American. These percentages are well above the national averages for diversity in physics Bachelor of Science graduates.

Etelman also works to support young people in their studies and hires young researchers at the start of their career. “We actively work to mentor undergraduate student researchers and encourage them in their pursuit of other internship opportunities, such as with NASA and the US Department of Agriculture,” says Brice. “We also support high school students in various observatory research initiatives to engage and inspire them to pursue a degree and career in STEM.”

LINKS WITH THE WIDER COMMUNITY

In 2019, the observatory joined an international collaboration of telescopes across the globe focused on studying and understanding the elusive explosions in space that lead to the emission of powerful bursts of gravitational waves. The Global Rapid Advanced Network Devoted to Multi-messenger Addicts collaboration is a worldwide partnership of 25 ground-based telescopes in Europe, Asia, Australia, North America and the Caribbean.

The observatory also collaborates with the University of Western Australia’s Zadko Observatory, and with the Robotically Controlled Telescope operated by a consortium of universities including South Carolina State University and the University of Western

Kentucky. These collaborations are focused on complimentary observation that provides more complete and continuous coverage of the optical counterpart of gamma-ray bursts and monitors galaxies that previously hosted ultra-long gamma-ray bursts.

VISIONS FOR THE FUTURE

Brice envisions an increase of scientific production in the observatory’s key research areas, as well as further diversification of the research activities available to students. “We are working to open up to tourism and astrotourism activities, as well as agrotourism,” says Brice. “We want to pave the way for more scientists, undergraduate researchers, community members and visitors to study and take in the abundant flora that call Etelman’s multiple-tiered gardens home.”

David believes that the success of the facility reflects the ambition and talent of the territory, which shows no signs of stopping. “The observatory has grown in prominence in the research community over the past 10 years due to the increase in commitment of faculty and students at UVI to pursue physics research and physics and astrophysics careers,” explains David. “The physics programme at UVI continues to grow in size and productivity each year. UVI has recently become among the nation’s leading HBCUs in producing physics graduates each year. We look forward to introducing more degree students to the excitement of astrophysics research and the potential for future careers in a wide range of STEM fields. The multidisciplinary nature of the work we do at Etelman provides a great training ground for students to begin their career path toward many different specialty areas. Our physics graduates are pursuing careers in fields including astrochemistry, renewable energy, medicine, aerospace engineering, computational biology and investment banking. The Etelman Observatory has been a launching point for a remarkably diverse group of career paths and we look forward to continuing that in the future.”

Etelman is a learning establishment forging an exciting future – will you be part of it?



DR BRICE ORANGE

Executive Director of and Astrophysicist at the Etelman Observatory, St. Thomas, United States Virgin Islands and CEO of OrangeWave Innovative Science, South Carolina, USA



FIELD OF RESEARCH

Solar Physics, Applied Electromagnetics Instrumentation



DR DAVID MORRIS

Director of the Etelman Observatory and Associate Professor of Physics at the University of the Virgin Islands, St. Thomas, United States Virgin Islands



FIELD OF RESEARCH

Observational Astrophysics Instrumentation



FUNDERS

The Etelman Observatory and its staff gratefully acknowledge support from: NSF EIR Award 1901296, NASA MUREP MIRO award NNX15AP95A, NASA MUREP MIRO award 80NSSC21M0001, NASA EPSCoR award 80NSSC17M0048, NASA EPSCoR award 80NSSC19M0060, NASA South Carolina Space Grant award NNX15AL49H, NAS Gulf Research Program award 2000009514, US Geological Survey to the Virgin Islands Water Resources Research Institute award G16AP00089, FEMA award HMGP-FEMA-4340-0050, and UVI Greatness Through Innovation award 260380.

STUDENT PROFILE: RUEL MITCHEL



Ruel completed a dual-degree in engineering and applied mathematics at the University of the Virgin Islands and the University of South Florida.

the nature of solar variability and atmospheric redistribution processes.

WHAT SUPPORT DID YOU RECEIVE?

I was mentored by Dr Brice Orange, who provided guidance, emotional support and motivation, as I grew confident in exploring my career paths, future goals, building leadership skills and understanding corporate cultures.

WHAT MAKES ETELMAN SUCH A SPECIAL PLACE?

Etelman is the only observatory in the Virgin Islands and it houses the only research grade automated Cassegrain telescope I'm aware of in the Lesser Antilles. The observatory staff are very enthusiastic and have a great group of volunteers. It is also led by vetted astronomers and has university faculty who aid one another in research and career growth.

WHAT DID YOU GAIN FROM YOUR TIME AT THE OBSERVATORY?

I truly grew as a young scientist and engineer; I'm confident in myself and my skills as a result. When I left my home university in the Virgin Islands to study engineering, I had an advantage over many of my peers in terms of technical experience and critical thinking skills. During the tough moments in my education, experience I acquired from the mentoring at Etelman helped me stay focused and avoid emotional and mental pitfalls.

WHAT AMBITIONS HAVE YOU SET YOURSELF FOR THE FUTURE?

I am trying my best to become a great engineer/scientist, with great experience in multiple technical and non-technical disciplines. Hopefully, in the future, I can pass down everything and mentor a protegee myself.

WHAT LED YOU TO THE ETELMAN OBSERVATORY?

While studying at UVI, I had the opportunity to apply to work on solar astrophysics during a summer research experience. I saw it as an opportunity to grow as a young scientist, as well as begin my journey into a scientific discipline.

WHAT RESEARCH DID YOU WORK ON?

While at the observatory, my research focused on analysing the Solar Physics Feature Database catalogue to investigate

EXPLORE A CAREER IN ASTROPHYSICS

- *Study in the USA* has a section dedicated to studying astrophysics and astronomy which includes a map you can click on to find a school in the area you are interested in studying at:
www.studyusa.com/en/field-of-study/354/astrophysics-and-astronomy
- *Science for the Public* has put together an exhaustive list of resources relating to astronomy and astrophysics:
www.scienceforthepublic.org/resources/resources-astronomy-astrophysics
- According to nationalcareers.service.gov.uk/job-profiles/astronomer, salaries can range anywhere between £15,000 and £60,000, depending on experience.

PATHWAY FROM SCHOOL TO ASTROPHYSICS

Brice and David are keen to emphasise the importance of mathematics in becoming an astrophysicist. "First learn math. Then learn more math. Then, once you know math well, start taking physics courses," says David. "Once you have learned the basics of physics, you can begin learning astronomy, which is where the fun begins!"

You will need a degree in a relevant subject for postgraduate study.

nationalcareers.service.gov.uk/job-profiles/astronomer

BRICE AND DAVID'S TOP TIPS

- 01 Science is everywhere, and everything, you just have to know how to listen and find what parts of it set your heart and brain on fire.
- 02 Never forget where you come from. Combine that with high levels of passion and dedication and you will be on the path to success.
- 03 Do your best to listen to what you are being told and exhibit critical thinking and reasoning skills.
- 04 Commit to every step of your journey, whether you know where it will lead or not. Try and enjoy it!



Dr Brice Orange lecturing two UVI undergraduate physics students (on the roof of the Etelman Observatory) about equipment to study the August 2017 Solar Eclipse. (Credit: Trude Johansson-Orange)

HOW DID BRICE BECOME AN ASTROPHYSICIST?

I have been inspired by my father, and one of his favourite quotes: “knowledge is power”. He always encouraged, supported and pushed me to think beyond the limits of any box.

My success boils down to a relentless pursuit of my own metric – the measure of success rivals the vastness of your own mentality. In addition, my unwavering dedication to simultaneously pursue what I routinely heard was the supposedly unobtainable and my own happiness.

I had a moment I would call ‘eureka’, and others I fondly think of as happenstance. The eureka happened after graduating undergrad,

while I was working as a surf instructor. I realised that my passion and career, whatever they ended up metamorphosing into, would require much more involvement from my brain. So, I made the decision that it might be worth trying my hand at graduate school.

In addition to my main passion, the Sun-Earth system, my company, OrangeWave has allowed me to dabble in many science and Research & Development (R&D) things, which I love. So, here goes! I have been involved in solar atmospheric and plasma physics, robotic telescope control systems and system operations of robotic observatories, environmental/climate science and related

technology R&D, high-energy astrophysics, software engineering that supports diverse scientific research fields, vertical flight R&D, development of radiation shielding technology, and R&D for an experimental plasma physics/magnetic reconnection system to mimic solar flares.

I am an (extremely) small town/rural area kid, who loves all things to do with the ocean – particularly surfing – and spending time with family and friends, gardening, travelling, trying out new food, and trying (with an emphasis on trying!) to learn Norwegian from my Norwegian wife.

HOW DID DAVID BECOME AN ASTROPHYSICIST?

I have always been fascinated with the fundamental questions of where the Universe came from, if there is life elsewhere and how life began. These questions can only be approached through science, especially physics and astronomy.

Physics and astronomy are fields that allow you to dive deeply into understanding the world and the Universe around you through math and data. If you do it right, you see connections on all scales in the world around you, but it often takes tremendous patience and dedication to understand and demonstrate principles through observations that may sometimes take many years to accumulate. Sharing the sense of satisfaction that I derive from understanding and appreciating these connections with students

is one of my greatest satisfactions. It is gratifying to hear students express this same sense of wonderment.

Many years ago, I studied astrophysics as an undergraduate at the University of Massachusetts. As an undergraduate I did research at a small observatory, similar to Etelman. I trace my passion for the work I do now back to those days. After several years in aerospace contracting (after my Bachelor of Science in physics and astronomy), I returned to graduate school where I studied astrophysics using satellite observatories and, after graduate school, I worked at NASA’s Goddard Space Flight Center. Later, a relative happened to see an advertisement for a faculty position at the University of the Virgin Islands and to also take on directorship

of a small observatory, not unlike the one I did research at as an undergraduate! It seemed like a tremendous opportunity to build a program that would allow me to do the science that I was passionate about while also giving UVI’s students access to the same kind of hands-on science projects that I had as an undergraduate. It was a chance I couldn’t pass up!

Dedication, patience, and commitment to learning always have helped me throughout my career. I believe a scientist is a person who sees every day as a chance to study things around them and to learn – to look for connections that make seemingly different phenomena easier to understand in the aggregate.



SEARCHING THE SKIES

THE UNIVERSE IS FILLED WITH ONE BILLION TRILLION STARS – LOOK AT THE SKY ON A CLEAR NIGHT AND THE FEW THOUSAND THAT ARE VISIBLE ARE INCREDIBLE TO SEE. THE FASCINATION OF GAZING INTO THE VASTNESS OF THE UNIVERSE HAS LED DR BRAD NEWTON BARLOW, OF THE CULP PLANETARIUM AND HIGH POINT UNIVERSITY IN THE US, TO DELVE DEEPER INTO SPACE TO HUNT FOR A STRANGE TYPE OF STAR CALLED A HOT SUBDWARF

TALK LIKE AN ASTROPHYSICIST

ASTRONOMY – the study of the Universe

ASTROPHYSICS – a branch of astronomy which studies the physical processes and properties of the Universe

BINARY STAR SYSTEM – two stars which orbit each other

COSMOLOGY – a branch of astronomy which studies the origin and evolution of the Universe

PYTHON – a scripting language used in computer coding

RED GIANT – a star that has expanded to a tremendous diameter during the final stages of its lifetime

TYPE 1A SUPERNOVA – the explosion of a white dwarf upon exceeding its mass limit

VARIABLE STAR – a star whose brightness changes as we view it from Earth

WHITE DWARF – the extremely dense, Earth-sized remnant core of a dead star

subdwarf merges with its neighbouring white dwarf, it may explode to form a Type 1a supernova. Cosmologists use these supernovae to measure vast distances across the Universe and have shown that the expansion of the Universe is accelerating. We frequently observe Type 1a supernovae explosions in other galaxies, but astronomers have not caught a binary system just before it collides and explodes. Until now...

Brad helped discover a new binary system containing two stars so close together that they orbit each other in under two hours. “Earth takes 365 days to orbit the sun,” explains Brad, “but these two stars orbit in under two hours!” They are so close and orbiting so quickly that they are slowly spiralling in. Soon (in astrophysical terms, millions of years from now) the stars will interact. The white dwarf will explode as a Type 1a supernova, causing one of the most powerful and luminous events in the Universe.

SEARCHING FOR STARS

While few hot subdwarf stars were once known, the European Space Agency’s Gaia spacecraft recently discovered >30,000 new ones, giving a total of ~40,000 hot subdwarfs

The Universe is full of strange and wonderful things! Amongst the rarities that intrigue astrophysicists are hot subdwarfs – very hot, dense stars. Researchers think they form from red giants stripped of their outermost atmosphere by gravitational interactions with another nearby star. Consistent with this theory, almost all hot subdwarfs are found in binary systems, existing in orbit with another

star. As Dr Brad Newton Barlow, Director of the Culp Planetarium and Associate Professor of Astrophysics at High Point University in the US, explains, “Hot subdwarfs are definitely not a ‘normal’ type of star.”

STARS COLLIDING

Some hot subdwarfs have a hot binary companion such as a white dwarf. If a hot



in our part of the Milky Way. Most interesting of these are the variable hot subdwarfs, whose brightness varies as we observe them from Earth.

This variation occurs if the companion star is a white dwarf, which have intense gravitational fields. This distorts the hot subdwarf from a sphere to an ellipsoidal shape. As the binary stars orbit, different sides of the ellipsoidal hot subdwarf will face Earth, causing an apparent change in the observed brightness.

This variation also occurs if the hot subdwarf has a cooler companion. As the two stars orbit, the cooler companion will block, or ‘eclipse’, some of the light from the hot subdwarf, preventing it reaching Earth, so the observed brightness will decrease.

The traditional method of observing variable stars involves pointing an Earth-based telescope at the star for several hours and recording a series of images. The brightness of the star in each image is plotted against time to produce a “light curve”, allowing variations in brightness to be quantified.

With 40,000 hot subdwarfs, it would take far too long to study them all this way. Moreover, most of this expensive telescope time would be wasted, as most hot subdwarfs are not variable. Brad, along with his students and collaborators, devised a new method to ascertain which stars they should focus investigations on.

THE GAIA ERROR BAR METHOD

Brad and the team realised that when the Gaia spacecraft records a star’s brightness, the associated error can indicate whether the star is variable. “Take two stars with the same brightness – one that is constant in time, another that changes in brightness,” explains Brad. “The scatter in Gaia’s brightness measurements will be larger for the variable star, because it has a different brightness

each time Gaia observes it.” This means that without a light curve, requiring hours of telescope observations, Brad can now identify potential variable stars just from the anomalously high error bars on their brightness measurements.

This novel method is highly efficient, with a >95% success rate. From the 40,000 known hot subdwarfs, Brad’s team have identified 2000 stars that are potentially variable, and therefore of most interest for investigation. It would still take too long to study all these individually with Earth-based telescopes looking at small regions of the sky. Instead, astrophysicists need survey-oriented systems with large fields-of-view to acquire follow-up observations of numerous stars at the same time.

NASA’s TESS satellite was launched in 2018 to search for exoplanets, but the data it gathers can also be useful for those who want to examine the light curves of stars. TESS spends 27 days pointing at a sector of the sky, collecting a sequence of ~20,000 images. Once complete, it points to a new sector and collects images for another 27 days. This process will be repeated for several years, until the entire sky has been imaged.

LIMITED BANDWIDTH

Even though TESS is imaging all the stars it sees, many of these observations are ‘wasted’ because there simply is not enough bandwidth available to downlink all the data back to Earth.

Astronomers who want to access these observations must compete against each other, making a case for why the data they are interested in deserves to be sent to Earth. Brad’s team is fortunate to have had two cases accepted. These are providing them with 10 million individual brightness measurements from TESS, allowing them to generate light curves for several thousand hot subdwarf stars.



DR BRAD NEWTON BARLOW

Director of the Culp Planetarium and Associate Professor of Astrophysics, High Point University, North Carolina, USA

FIELD OF RESEARCH

Stellar Astrophysics

RESEARCH PROJECT

Investigating hot subdwarf stars

FUNDERS

NASA and the National Science Foundation

RUNNING CODE

Once data have been downlinked to Earth, Brad and his team process and analyse them using computer code they wrote in Python, looking for any periodic signals in the stars’ light curves. They classify new variable stars by running code to examine the shape of the light curve, then more codes help to determine important parameters such as the masses and radii of the stars in the binary system.

WHAT NEXT FOR THE TEAM?

This project is generating a lot of data for Brad and his team. To date they have discovered over 100 new variable hot subdwarf stars. Some of these are hot subdwarfs in orbits with red dwarfs and white dwarfs, which will help astrophysicists understand how hot stars evolve in binary systems. Other systems turned out not to be hot subdwarf binaries at all, but strange “cataclysmic variables”, in which mass is transferring from a red dwarf to a white dwarf. Many of the new variables have yet to be classified.

The team will identify which of these systems are most interesting for further research. They will apply to visit Earth-based telescopes, where they will conduct important follow-up observations enabling them to analyse these incredible new stars.

ABOUT ASTROPHYSICS

To study the physics of the Universe, an astrophysicist spends a lot of time writing and debugging computer code to run simulations or analyse data. "On some days this goes smoothly," says Brad. "But I've spent entire days banging my head against my keyboard, trying to find one small error in my code!"

While a physicist, biologist or chemist can go into their laboratory and control their experiment, astronomers do not have such luxuries. "The Universe provides us a one-way information stream in the form of light and gravitational waves," explains Brad. "The

inability to control the experiment, or to even see what we are studying, forces us to be very careful when interpreting our results."

"It's fun to uncover the secrets of the Universe!" says Brad. "I enjoy the thrill that comes with making new discoveries. It makes me feel like I'm a part of something bigger than myself."

For Brad, one of the most rewarding aspects is watching his students develop into scientists and make discoveries of their own. He has a rule for everyone who works with him: if they

discover something new, they must not tell anyone else about it, including Brad, for 15 minutes. Why? "For those 15 minutes, they are the only being in the entire Universe to know that bit of information," explains Brad.

PATHWAY FROM SCHOOL TO ASTROPHYSICIST

At school, take maths, physics and computing courses, and Brad recommends gaining experience in coding. In college/university, your courses will focus on astronomy, physics, maths and computer science. Brad advises, "No matter what stage you're at, reach out to faculty members or astronomers to see if you can participate in the research they do."

Many astrophysicists will have a degree in astronomy, astrophysics or space science, but a broader degree in physics, maths or geophysics can also lead to a career in astrophysics.

HOW DID BRAD BECOME AN ASTROPHYSICIST?

As a child I was interested in two things: astronomy and music. I received my first telescope when I was 10 and I spent uncountable nights observing the sky with it. Around the same time, my grandparents taught me how to play the piano and I started writing my own musical compositions. I absolutely love listening to movie soundtracks (think Hans Zimmer and John Williams). Aside from being an astronomer, my dream job has always been to compose scores for movies.

When I was growing up, my dad took my brother and me outside to watch a meteor shower. To this day, I remember how the shooting stars looked like they were coming out from behind the giant oak tree in our yard. I was thought that the tree might catch on fire!

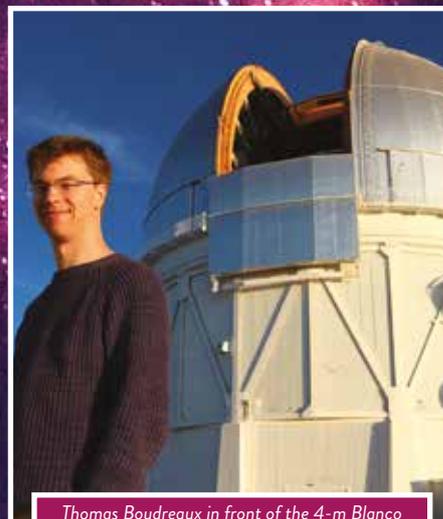
I think a combination of curiosity, creativity, patience and grit have contributed to my success as a scientist.

If I need to unwind after a long day, I immediately go to the piano and start playing and writing music. I actually keep a keyboard in my office so I can take short, creative breaks throughout the day.

When I was a graduate student, I helped write a very small piece of the control software for the Goodman spectrograph on the 4.1-m SOAR Telescope in Chile. This instrument is now used by astronomers around the world to make exciting observations and discoveries, and it makes me proud to know I played even a small role in making this possible.

BRAD'S TOP TIP

Don't ever doubt your own abilities because others around you seem smarter or more confident than you are. Even the best scientists in the world make mistakes and doubt themselves from time to time.



Thomas Boudreaux in front of the 4-m Blanco Telescope on Cerro Tololo in Chile.

STUDENT RESEARCHERS

Brad explains, "I've always believed that the best way to learn science is simply to do science." His students help to write proposals for time allocations on observational telescopes, travel with him to collect telescope data, write code to process and analyse data, and present results at conferences and in journals.

THOMAS BOUDREAUX

*Astrophysics graduate student
Dartmouth College, USA*



I had wonderful mentors all throughout my education, but I decided to pursue science in pre-school after looking at a picture book with a picture of all nine (as there were at that point) planets. I have never looked back.

My role as an undergraduate researcher with Brad evolved over time. At the start, I was analysing data for Brad. Later on, I was proposing projects and driving them while he guided the bigger picture.

How to be a good programmer was the most important hard skill that I picked up. More nebulously, I learnt how to think about and frame research questions in my head.

Having an idea that you can implement is the best feeling in the world. For me, this means programming it into a computer. It either works, or it doesn't, but the act of taking that idea and making it into something testable is incredibly satisfying.

I fell in love with stellar physics while working with Brad, and every time I learn something new about stars my mind is blown.

I am currently working on a 50-year-old code base which models how stars live and die. The way people programmed in the 1970s was very different and that, in combination with the

complexity of the code, makes it very difficult to work with.

A few years ago, I published a paper on the application of deep learning to the classification of variable stars. It wasn't super complex in hindsight, but it was the first project I fully conceived and drove to completion. I am very proud of that.

Make a connection to a faculty member or teacher if you can. I would not be where I am today without amazing mentors from grade school, high school, college, and now graduate school.

RODRIGO CATALAN-HURTADO

*Biochemistry graduate student
Eukaryotic Pathogens Innovation Center, Clemson University, USA*



I decided to pursue science after my first biology class in high school when our teacher introduced the topic of gene editing. I was amazed at how far we had advanced in biology, and I wanted to take part in that advancement.

As an undergraduate under Brad's guidance, I researched the blue supergiant binary system HD 318015. We obtained optical spectra of the system from a telescope in the Chilean Andes, and we wrote specialized Python code to measure the individual velocities of its stars.

Studying astrophysics helped prepare me for my current research

in biology. I learnt the importance of troubleshooting and how to perform statistical data analysis, crucial skills in both astrophysics and biology. As a biologist, I regularly put these into practice.

I enjoy learning new experimental techniques in biology that help me answer questions relevant to my research subject.

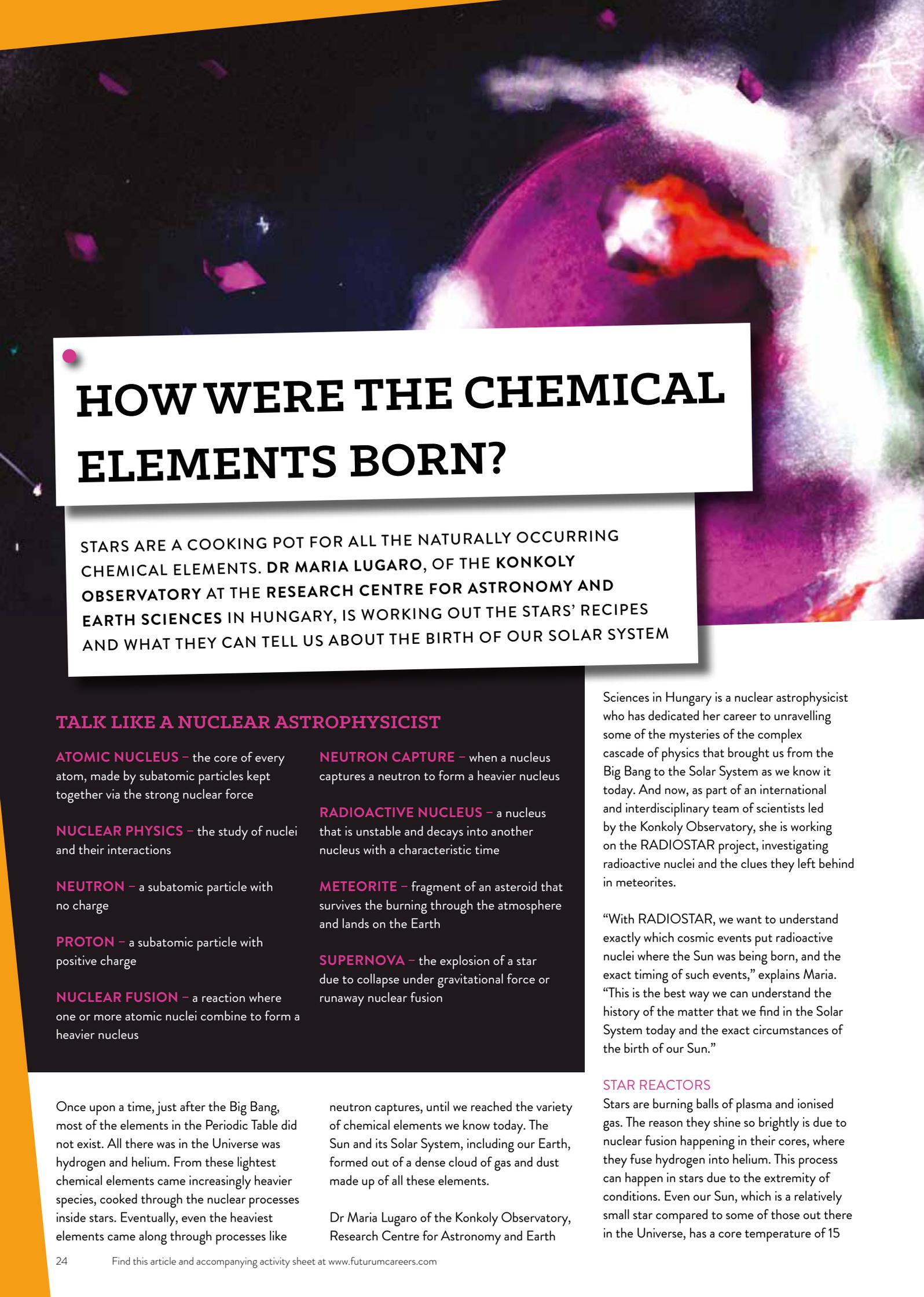
My greatest challenge in my current research is having to start from the beginning when it comes to my experiments as there is not much known about the molecular pathway I am studying. I must develop experimental procedures that will thoroughly and efficiently

answer the bigger question that I am addressing.

Achieving a Bachelor of Science degree and getting into graduate school in my field of interest are two of my proudest achievements.

With a goal of working for a biotechnology company, I am currently pursuing a PhD degree in a field that I am passionate about.

I was fortunate enough to meet people that helped guide me to where I am today. I think it is important to network with people in your field of study because they will be of great assistance in the future.



HOW WERE THE CHEMICAL ELEMENTS BORN?

STARS ARE A COOKING POT FOR ALL THE NATURALLY OCCURRING CHEMICAL ELEMENTS. DR MARIA LUGARO, OF THE KONKOLY OBSERVATORY AT THE RESEARCH CENTRE FOR ASTRONOMY AND EARTH SCIENCES IN HUNGARY, IS WORKING OUT THE STARS' RECIPES AND WHAT THEY CAN TELL US ABOUT THE BIRTH OF OUR SOLAR SYSTEM

TALK LIKE A NUCLEAR ASTROPHYSICIST

ATOMIC NUCLEUS – the core of every atom, made by subatomic particles kept together via the strong nuclear force

NUCLEAR PHYSICS – the study of nuclei and their interactions

NEUTRON – a subatomic particle with no charge

PROTON – a subatomic particle with positive charge

NUCLEAR FUSION – a reaction where one or more atomic nuclei combine to form a heavier nucleus

NEUTRON CAPTURE – when a nucleus captures a neutron to form a heavier nucleus

RADIOACTIVE NUCLEUS – a nucleus that is unstable and decays into another nucleus with a characteristic time

METEORITE – fragment of an asteroid that survives the burning through the atmosphere and lands on the Earth

SUPERNOVA – the explosion of a star due to collapse under gravitational force or runaway nuclear fusion

Once upon a time, just after the Big Bang, most of the elements in the Periodic Table did not exist. All there was in the Universe was hydrogen and helium. From these lightest chemical elements came increasingly heavier species, cooked through the nuclear processes inside stars. Eventually, even the heaviest elements came along through processes like

neutron captures, until we reached the variety of chemical elements we know today. The Sun and its Solar System, including our Earth, formed out of a dense cloud of gas and dust made up of all these elements.

Dr Maria Lugaro of the Konkoly Observatory, Research Centre for Astronomy and Earth

Sciences in Hungary is a nuclear astrophysicist who has dedicated her career to unravelling some of the mysteries of the complex cascade of physics that brought us from the Big Bang to the Solar System as we know it today. And now, as part of an international and interdisciplinary team of scientists led by the Konkoly Observatory, she is working on the RADIOSTAR project, investigating radioactive nuclei and the clues they left behind in meteorites.

“With RADIOSTAR, we want to understand exactly which cosmic events put radioactive nuclei where the Sun was being born, and the exact timing of such events,” explains Maria. “This is the best way we can understand the history of the matter that we find in the Solar System today and the exact circumstances of the birth of our Sun.”

STAR REACTORS

Stars are burning balls of plasma and ionised gas. The reason they shine so brightly is due to nuclear fusion happening in their cores, where they fuse hydrogen into helium. This process can happen in stars due to the extremity of conditions. Even our Sun, which is a relatively small star compared to some of those out there in the Universe, has a core temperature of 15



DR MARIA LUGARO

ERC-CoG and Lendület project leader
Konkoly Observatory, Research Centre
for Astronomy and Earth Sciences,
Eötvös Loránd Research Network,
Budapest, Hungary

FIELD OF RESEARCH

Astrophysics

RESEARCH PROJECT

RADIOSTAR: Radioactivities from Stars
to Solar Systems.

FUNDER

European Research Council (ERC) ERC-
2016-COG - Grant Agreement 724560

million degrees Celsius. In comparison, blast furnaces for melting metals and making steel on Earth only reach around 1500 degrees Celsius!

Hydrogen is essentially food for stars, and when a star begins to run out of this fuel, it starts to fuse heavier and heavier elements. Massive, dying stars running out of hydrogen will start to expand, creating new elements as they go, before they eventually explode in a very luminous supernova, expelling all these elements into space.

“Of the 83 stable and long-lived chemical elements, roughly 80% are heavier than iron,” says Maria. “These are uncommon elements and most of them have strange, sometimes fantastic names, from praseodymium to iridium, and dysprosium to promethium.” RADIOSTAR is aiming to understand how these heavy elements were created in the cosmos.

HEAVY ELEMENTS

Making the heaviest elements is not easy. “How did nature manage to combine very light particles like the helium atomic nucleus, with 2 protons and 2 neutrons, into something heavy like the nucleus of lead with 82 protons and 126 neutrons?” asks Maria.

The answer lies in a process called neutron capture. It has long been known that heavier

elements in stars must be created by nuclei capturing neutrons, but how that process works has remained something of a mystery. This is because neutrally-charged neutrons rapidly decay into positively-charged protons with a half-life of about 10 minutes, meaning that free neutrons are difficult to make.

Maria has been particularly fascinated by neutron-capture processes in stars and what their radioactive products can tell us about the history of our Solar System. Especially, she wants to learn about the birth of our Sun from radioactive nuclei made by neutron captures and brought to Earth in meteorites. Information from meteorites tells us how the specific conditions in space and time when our Sun was born resulted in the Solar System we have today. Maria says, “There must have been cosmic events that occurred not too early, yet not too late, and not too far, nor too close, to have produced the exact radioactive mix that was present at the birth of the Sun.”

The RADIOSTAR team can use these radioactive nuclei as clocks, tracing back and determining what the Sun’s original family must have looked like at the moment our Solar System was born. Data from analysis of radioactive elements found in meteorites, using techniques such as mass spectrometry, enables the team to compare the proportions

of nuclei of different mass, which, when combined with knowledge of the half-life of each radioactive nucleus, allows calculation of when these elements were produced inside a star or a supernova.

KEY RESULTS

So far, Maria’s results, “strongly suggest that the Sun was born in a large, long-living stellar nursery. Our Sun had many siblings, and different stellar generations born at different times coexisted together in the nursery. Although the Sun left this birth environment a long time ago, this environment strongly shaped its formation and early evolution.”

The work of RADIOSTAR has also revealed that when massive stars exist in orbit with a companion star, they can interact in such a way that they eject more radioactive aluminium than lone stars, and that when a massive star collapses and explodes into a supernova, the dust that is created is very rich in heavy chromium. Now, Maria and the RADIOSTAR team will map all these puzzle pieces together to determine how these nuclei have voyaged across the Galaxy, and what role they have played in shaping our Earth as it looks today.

ABOUT ASTROPHYSICS

Have you ever looked up into the sky at night and wondered about the nature of all the stars and galaxies you can see? Astrophysics is about understanding all objects in space, from planets to stars, meteorites and galaxies. This includes understanding the physics of how they shine and interact, as well as the physics involved with how they came to be.

Astrophysics is a broad field with many different subdisciplines. Some astrophysicists create computational models, whereas others work at observatories trying to catch a glimpse of faraway planets. One subdiscipline is nuclear astrophysics, an interdisciplinary field that applies theories from nuclear physics to processes in environments in space. Nuclear astrophysicists are interested in the role that nuclear processes play in the lifecycles of stars and the formation of new elements. A lot of this work is focused on the physics of atomic nuclei.

Maria is a nuclear astrophysicist who studies nuclear reactions in stars. She explains, “I like the fact that my work combines different aspects of physics, from the nature of stars and galaxies, to the nuclear physics of the nuclei inside the stars, to the atomic physics in the spectra of stars, and even chemistry

and laboratory analysis, when dealing with data from solid meteoritic rocks.” Within such a broad topic, there are always new things to learn and discover. “Even though I have been working in this field for 30 years, I have never stopped learning,” say Maria. “There are always new perspectives to consider and new methods to tackle that bring me far away from my comfort zone. This is challenging and adventurous.”

While Maria is based at Konkoly Observatory in Hungary, the international team behind the RADIOSTAR project and the nature of her work mean Maria collaborates with a wide range of scientists. “I normally work with nuclear physicists,” she says. One such collaborative project (called LUNA) involves measuring nuclear reactions in a laboratory located deep underneath a mountain in Italy. The laboratory has been built more than 1 km underground so that the thick layer of rock above it prevents cosmic rays from the Sun interfering with the incredibly sensitive nuclear data that are being collected. “I also work with colleagues who analyse meteoritic rocks,” says Maria, “as well as astronomers who take and interpret stellar spectra.”

Nicholas Butler, an American philosopher,

once said, “An expert is one who knows more and more about less and less until he knows absolutely everything about nothing.” Maria disagrees with this. “It is a funny joke,” she says, “but in my experience this does not happen. As I have discovered more about my specific field of neutron captures in stars, I have also had to understand and link this knowledge to its many implications in other fields. So, I have also had to learn about chemistry, dust, meteorites, nuclear reactions, nuclear structure, etc.”

As astrophysicists discover more and more solar planets, a key aim will be to understand our Solar System’s place relative to all the other planetary systems in the Galaxy.

This will require greater understanding of the composition of our own Solar System, necessitating further studies of chemical elements, radioactive nuclei, the formation of the Sun and how our Solar System evolved. “The more we try to explore such questions, the more need there is to communicate between different fields,” says Maria. “One of the main challenges for an astrophysicist is to connect your own research to other areas of science, and the next generation of scientists needs to be ready for this.”

EXPLORE A CAREER IN ASTROPHYSICS

- Check out the *Royal Astronomical Society’s* career resources. They have interviews with people working in the field, and even hold competitions and events you can get involved with: ras.ac.uk/education-and-careers/careers
- *Space Careers* is a good resource to find out about opportunities like summer schools and astrophysics events: spacecareers.uk/?p=summer_schools
- Try contacting your local university or, if you have one, observatory to see if they have any work experience opportunities.
- *The Konkoly Observatory* has a dedicated visitor centre you can visit (www.svabhegyicsillagvizsgalo.hu/) and has helped organise the *International Olympiad of Astronomy and Astrophysics* (ioaa2019.hu). Maria’s team also takes in high school students for work experience, several of whom have co-authored scientific publications with the group!

PATHWAY FROM SCHOOL TO ASTROPHYSICS

You will need a bachelor’s degree in physics or a related subject such as mathematics, chemistry or natural sciences. Some universities, such as Surrey University in the UK, have dedicated astrophysics with nuclear astrophysics programmes. You can read more here:

www.surrey.ac.uk/undergraduate/physics-nuclear-astrophysics

A broad undergraduate degree is fine for all areas of science, specialisation is usually done through master and PhD programmes.

HOW DID MARIA BECOME AN ASTROPHYSICIST?

When I was young, I was always interested in dancing, specifically classical ballet, but also flamenco, and I studied dancing from the age of 3 to the age of 16. I wanted to be a dancer, or a dance teacher, but then things clearly went differently. About 10 years ago, I discovered I could still do ballet as an adult to keep fit, so I now have classes every week!

At high school, I studied Latin and ancient Greek, together with history, philosophy, mathematics and physics. At university, I wanted to pursue many topics, from history to political sciences, to physics and mathematics. My mum studied physics and she suggested that I try that. It was hard at the start because I was missing some background, but once I started passing exams with the top marks, I realised I very much enjoyed it, especially the theoretical subjects, from quantum mechanics to relativity. For my thesis, I chose to work in nuclear astrophysics because Professor Roberto Gallino at the University in Torino,

my hometown, explained to us students that inside stars and stellar explosions there is a full microscopic world of nuclear reactions, which not only powers starlight but also creates all the chemical elements! He also introduced me to meteorites and how we can use them to understand stars and the Sun, which I found even more fascinating.

I have always been a diligent student, and this is at the basis of any achievement: working very hard. One characteristic that has helped me a lot is that I have a very good memory. As you work, things become more and more complicated and remembering what you and other scientists have done and why, really helps to keep your mind clear and to stay on a meaningful path, instead of going around in circles.

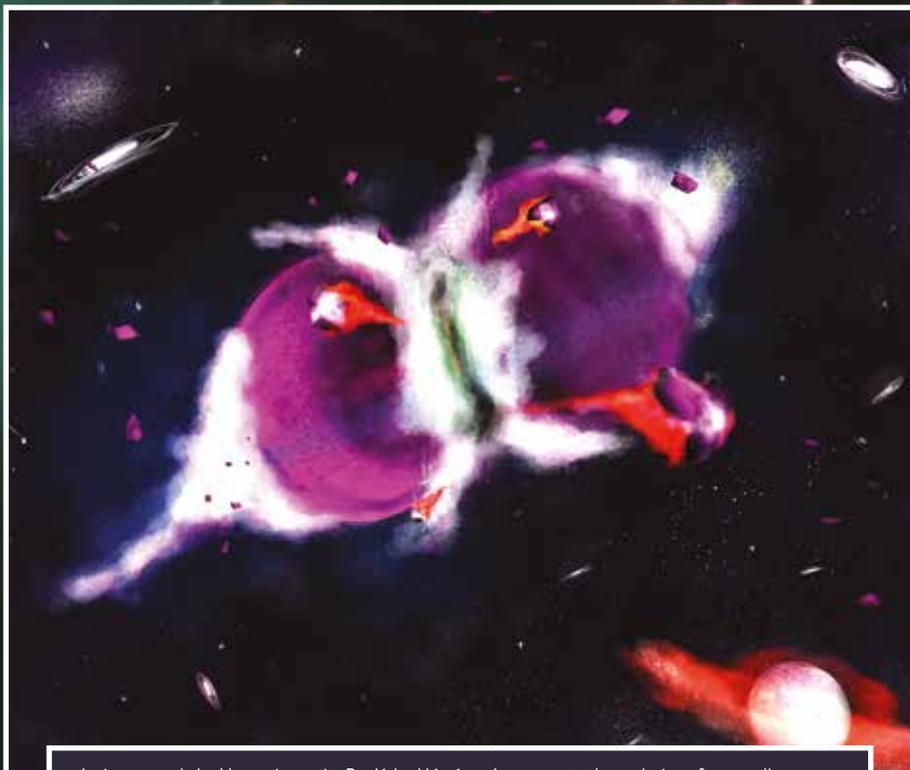
For a scientist, I think humility is like a superpower; it helps you to check your own work rigorously, to be open to new ideas and

to accept mistakes, failure, and criticisms, which inevitably come your way. As ballet dancer Margot Fonteyn said, “The one important thing I have learned over the years is the difference between taking one’s work seriously and taking oneself seriously. The first is imperative and the second is disastrous.”

I practise mindfulness twice a day and I try to avoid work and thinking about work out of work hours. The brain needs to rest to be able to keep on working at full efficiency. It is not easy to switch off, which is why I am trying to be more in control of what I think about, using the mindfulness practice. Luckily, I have a large family who helps distract me. I schedule three weeks of continuous holiday every summer, when I do not even check my emails. When those are finished, I always feel I have re-found who I am and can start having fun with science again!

MARIA’S TOP TIPS

- 01** Perseverance is a crucial skill to develop. Challenging yourself with harder tasks and being willing to stick to them is a way to get better at persevering and can help you enjoy your studies and work even more.
- 02** Read a lot and train your memory. Scientists need to read constantly to keep up to date with what is happening in their field and a good memory helps you not get lost in a labyrinth of old and new ideas.
- 03** Don’t be scared of mistakes. Challenging yourself in your studies and in science is all about learning to accept your mistakes and failures and keep going.



An image made by Hungarian artist Boglárka Mészáros. It represents the explosion after a stellar merger.

THE EXTRAORDINARY POTENTIAL OF NANOSCIENCE (FROM A RESEARCHER WITH EXTRAORDINARY POTENTIAL)

YASHASWI NALAWADE IS CURRENTLY WORKING ON HER PHD IN PROFESSOR JONATHAN COLEMAN'S LABORATORY AT TRINITY COLLEGE IN IRELAND. THE TEAM IS WORKING ON THE SYNTHESIS OF LOW-DIMENSIONAL NANOSTRUCTURES WHICH WILL HELP USHER IN THE NEXT GENERATION OF NANOTECHNOLOGY ACROSS A RANGE OF FIELDS

Nanotechnology is a branch of science that is concerned with working at the nanoscale, that is, materials that are around 1 to 100 nanometres. One nanometre is one billionth of a metre, which is unimaginably small – but these materials offer enormous potential for the development of a range of different technologies that could shape the world of the future. For instance, electronics is increasingly reliant on nanomaterials and the rise of 2D and 3D printing has led to a need for researchers to invent and/or develop materials that are suitable to print electronics.

To print electronics, ink is needed – but not just any ink. These inks need to be conducting, semi-conducting or insulating (which is also known as dielectric). With these requirements in mind, Yashaswi Nalawade is working at Professor Jonathan Coleman's laboratory, which is based within Trinity College at the University of Dublin in Ireland. Yashaswi is a PhD student with a keen interest in physics and nanoscience but also motivated by the ways her work contributes to overcoming some of the problems society will face in the future.

WHY IS THERE A NEED FOR YASHASWI'S RESEARCH?

There has been a recent shift in nanoscience

from the production and characterisation of 2D nanomaterials from layered crystals, to optimising and tailoring functional inks that are suitable for printing electronics. The growth in printed transistors and supercapacitors needs to be supported by a parallel growth in printed dielectrics, and Yashaswi's investigations seek to facilitate this. "My research involves synthesising and optimising insulating inks – i.e. going from a dielectric layered crystal to 2D nanosheets of insulating nature which can then be tailored into inks to be printed," explains Yashaswi. "The field of printed electronics, albeit very young, has shown promise in everyday applications to replace silicon-based devices. It allows for the development of wearable electronics, cheap, flexible and disposable devices which could have major societal impact and change our relationship with technology. It can also facilitate research that incorporates nanotechnology in sustainable energy and will help us make advancements in solar panels, wind turbines, etc."

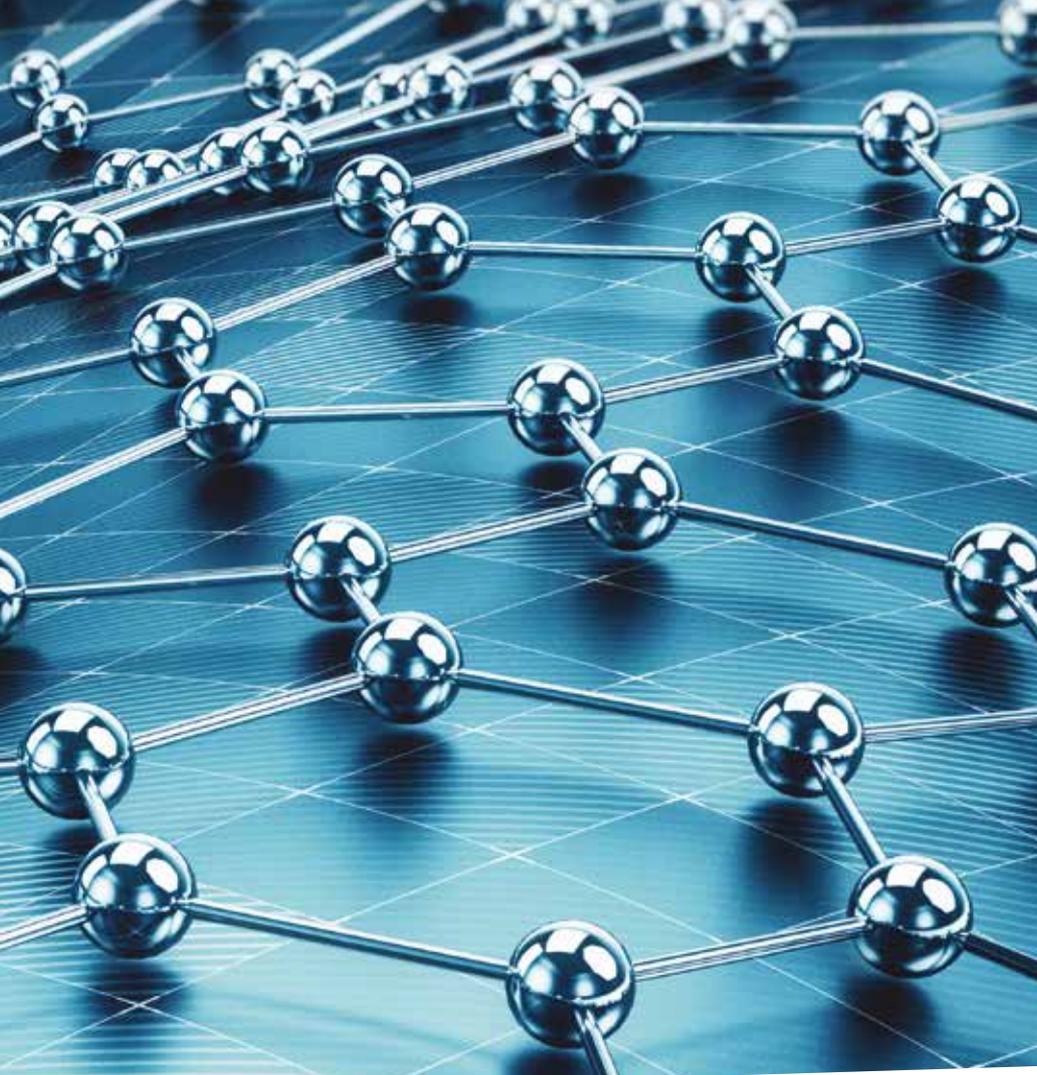
HOW IS THE LABORATORY SYNTHESISING NANOMATERIALS?

While the methods for synthesising nanomaterials are quite straightforward – they can be done with household items, such as

graphite from pencils and a kitchen blender! – developing these materials into complex designs and devices is where the challenge for Yashaswi and her colleagues lies.

The bonding in layered crystals is such that the atoms in the same plane are bonded by strong covalent bonds, whereas the interlayer bonding is due to the weaker 'Van der Waals' attraction (where the interaction between atoms depends on how close together they are). This enables the team to separate the layers and produce 2D nanosheets. "We use a technique called Liquid Phase Exfoliation (LPE) to synthesise our 2D nanomaterial dispersions. Powder of the bulk crystal is mixed with a specific solvent and sonicated, i.e. subjected to ultrasound energy for several hours," says Yashaswi. "The sonic energy creates bubbles or 'cavitations' within the liquid, which, on collapsing, release large amounts of shear energy that splits apart the layers in the crystal, thus producing 2D sheets in the liquid dispersion."

The nanosheets produced by this technique are a range of sizes and thicknesses. From there, the team use a technique called Liquid Cascade Centrifugation, which involves subjecting the dispersion to centrifugation so that the centrifugal force pulls the material



YASHASWI NALAWADE

Chemical Physics of Low-Dimensional Nanostructures Group, School of Physics, Trinity College, University of Dublin, Ireland



FIELD OF RESEARCH

Physics and Nanoscience



RESEARCH PROJECT

Yashaswi is working on the synthesis of low-dimensional nanostructures, including graphene, dielectric inks and boron-nitride nanotubes. The findings will facilitate research incorporating nanotechnology in a wide range of fields and applications.



FUNDERS

Yashaswi’s work is supported by her supervisor, Professor Jonathan Coleman. Professor Coleman’s research group is funded by the European Research Council and Science Foundation Ireland

out of the solution. Interestingly, the size of the nanosheet extracted is dependent on the speed at which the centrifuge is run at, so the higher the speed, the smaller the nanosheets.

WHAT MATERIALS IS THE TEAM FOCUSED ON?

The team that Yashaswi is a part of is working on the synthesis of low-dimensional nanostructures, including graphene, the aforementioned dielectric inks, and boron-nitride nanotubes. Graphene is produced from graphite and was the material that gained the field of 2D nanomaterials attention around the world. Graphite is a well-known conductor of electricity, but graphene boasts even better properties, such as high electrical conductivity and high thermal conductivity. In addition, a sheet of graphene can be more than 50 times stronger than steel and as pliable as rubber!

Boron-nitride (BN) has a structure that is almost the same as graphene but is also insulating. Both graphene and BN are easily available, cheap, non-toxic and easy to handle, making them extremely suited to a range of applications.

In addition, the team works extensively with TMDs (Transition Metal Dichalcogenides) – a group of semiconducting materials which can be exfoliated to make semiconducting

nanosheets, which allow the fabrication of transistors and optoelectronic devices, etc.

WHAT IS YASHASWI’S ROLE IN THE RESEARCH?

Yashaswi investigates dielectric nanomaterials and the deposition of dielectric films suitable for printed electronics. This involves the synthesis of dielectric nanosheets in dispersion and tailoring them into an ink that is suitable for printing. “Recently, I have contributed to this research by publishing a paper which details the liquid phase exfoliation of bismuth oxychloride (BiOCl) nanosheets, a high permittivity insulating material and further demonstrating BiOCl dielectric capacitors deposited using an aerosol-jet printer,” explains Yashaswi. “A stacked heterostructure was printed with graphene electrodes sandwiching an insulating film of BiOCl. The working of the capacitor was studied to characterise the quality and properties of the dielectric films.”

The publication of Yashaswi’s first paper – while she is working on her PhD – is a major encouragement for her and a sign that she is working in the right field. The feeling of satisfaction and pride when your research has been published can hardly be overstated and it really is a remarkable achievement. It will also likely be the first paper of many!

WHERE DOES YASHASWI SEE HER RESEARCH HEADING?

Given that Yashaswi has demonstrated that BiOCl is a strong candidate for dielectric films used in printed devices (i.e. it has a high dielectric constant and has been demonstrated to be suitable for printing), her research will likely usher in a move towards further characterisation of 1D and 2D dielectric materials and their composites. Further research needs to be conducted to improve specific properties of BiOCl, which may even require adding other materials to form composites that boast amazing properties. Whatever happens in the future, the fact is that printing electronic devices heavily relies on dielectric films and inks, so Yashaswi’s research will bring immense value to the field of nanotechnology and help to shape the future developments within it.

ABOUT PHYSICS & NANOSCIENCE

It is mind-blowing that scientists have found a way to work with materials that are so extraordinarily small. Manipulating and making use of materials that are smaller than the width of a human hair sounds like something from the realms of science fiction, but it is science fact! At the incredibly small scales we are talking about, materials demonstrate properties that simply do not exist on larger scales, which is exciting for a range of different fields because what was once thought impossible to achieve is now possible.

Nanomaterials have a high surface area to volume ratio, which means they can function as extremely effective catalysts and speed up chemical reactions. The possibilities within the field were thought unrealistic just a few years ago, which should tell us that the possibilities for the future are probably beyond what most of us can imagine today.

Yashaswi is just starting out in her research career, but she will be a doctor before long and has already had one of her research papers published. It appears that her career pathway is going to be very exciting and her work could help us overcome issues regarding climate change, global warming and the development of sustainable technologies (as well as many other applications).

WHAT DOES YASHASWI FIND INTERESTING ABOUT HER WORK?

Yashaswi believes that working in a lab is very rewarding because you get to build something from scratch, and getting that something working is a very satisfying feeling! In her lab, she is surrounded by other people with a keen interest in physics and nanoscience, and they can all ask each other questions and work together to design experiments to answer the questions they have. "I was sure I wanted to pursue something in applied physics that involved doing experiments and working with my hands in a lab," says Yashaswi. "With that in mind, nanoscience was the obvious choice. It is a fast-growing field of applied physics and has much scope in commercial applications."

WHAT ARE THE MAIN MISCONCEPTIONS THAT PEOPLE HAVE?

"People think that nanoscience is making tiny robots that would be inserted into our bodies and swim around and fix problems, but these are misleading notions," says Yashaswi. "In reality, when we reduce the size of objects to nanoscale, they behave very differently to their 'bulk' version. For example, if we were to build a nanorobot to swim in your blood, it would experience a much higher viscous force from the medium – it would be like us trying to swim

in oil. This would require the robot to have a motor to propel it forward. But of course, it is unrealistic to have a motor that powerful which is that small."

WHAT WOULD BE YASHASWI'S DREAM PROJECT TO WORK ON?

Yashaswi is keen to work on something related to sustainable energy technology – and nanoscience has extraordinary potential in this area. It is worth remembering that nanoscience is still in its infancy – it only began around 12 years ago, but researchers like Yashaswi will help ensure that nanotech becomes an ever-present part of our daily lives.

PATHWAY FROM SCHOOL TO NANOSCIENCE

Yashaswi says that students should certainly consider studying physics, chemistry and maths in school and beyond. If there are any statistics classes or modules offered you should think about taking them, as they will prove to be a big help for budding nanoscientists.

2 or 3 A levels, or equivalent, including maths and a science for a degree.

Relevant degree subjects include nanoscience, physics, chemistry, electronics engineering, materials science and computer science. You will usually need a degree or a postgraduate master's qualification in nanotechnology, or a related course which includes nanotechnology.

<https://nationalcareers.service.gov.uk/job-profiles/nanotechnologist>

EXPLORE A CAREER IN NANOSCIENCE

- Nanowerk goes into some detail about what nanotechnology is and why it is important. The site also includes a wealth of information on different nanomaterials, resources and jobs within the field:

https://www.nanowerk.com/nanotechnology/introduction/introduction_to_nanotechnology_1.php

- FutureLearn hosts introductory courses on how nanotechnologies are applied in various fields, such as healthcare. You can join many courses for free and it is conducted 100% online, so you can study from anywhere:

<https://www.futurelearn.com/courses/nanotechnology-health>

- As a PhD student, you receive a stipend of around £16,000 to £18,000 a year, for a period of four years.

- The salary for an experienced nanotechnologist varies, depending on the level of experience and the specific job title, with the upper pay scale around £40,000:

<https://nationalcareers.service.gov.uk/job-profiles/nanotechnologist>



Yashaswi performing I-V measurements on printed capacitors placed in a vacuum chamber.

HOW DID YASHASWI BECOME A NANOSCIENTIST?

WHAT WERE YOUR INTERESTS AS A CHILD?

I was always only ever interested in science as a child. This was probably because I was constantly exposed to it as both my parents are from a science background too! I wouldn't say I was a voracious reader or was watching loads of animal/nature shows, but there was always an underlying curious mind and any problem was approached scientifically.

WHO OR WHAT INSPIRED YOU TO BECOME A SCIENTIST?

I was introduced to a lot of big picture physics questions from a young age by my father – he would always tell me the problems scientists and mathematicians were working on. This instilled a curiosity in me to be involved in these topics myself.

WHAT ATTRIBUTES HAVE MADE YOU SUCCESSFUL AS A SCIENTIST?

I am naturally curious, always asking why and how until I am satisfied with the answer, always questioning why things are the way they are. Most importantly, I'm not afraid to say I don't know or understand something. There's no shame in that and, in fact, it helps you acquire more knowledge.

HOW DO YOU OVERCOME OBSTACLES IN YOUR WORK?

I actually work much better in a team than on my own – I am quite good at discussing a problem and troubleshooting with my group members. So, any time I encounter an obstacle, I find it helpful to discuss it with my colleagues or supervisor.

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

I am generally proud I haven't lost my interest and thirst for science – it's definitely not easy to maintain. Getting my PhD position in a well-renowned research group was a big moment for me and a step in the right direction! Now that I am in my final year and have published a paper, I feel much more confident I'm doing what I love. As of now, I hope in the future I become involved in something that is meaningful, with a clear goal towards bettering our lives (for example, I would love to be involved in researching sustainable energy technology), without losing my love of science.

YASHASWI'S TOP TIPS

- 01** Keep at it! You do not have to be a genius to have a career in science – you just have to work hard and have a genuine interest in it. Never be afraid to say that you do not understand something, especially as most people around you have the same questions that you do. Ask for help as much as you can!
- 02** Avoid specialising in one niche topic, as a broad understanding will provide you with the skills, knowledge and experience you will need to focus on a more specific area in the future. Instead of direct entry courses, perhaps consider choosing general science courses for your first years in college.
- 03** Ask for internships and work experience in labs during college as much as you can. A lot of professors are looking for summer students and it is a great way to get a taste of research before making any big decisions.



HOW CAN RADIOACTIVE ELEMENTS HELP US?

RADIOCHEMISTRY INVOLVES MAKING MOLECULES WITH RADIOACTIVE ATOMS. DR DAVIDE AUDISIO OF THE FRÉDÉRIC JOLIOT INSTITUTE FOR LIFE SCIENCES, PART OF THE FRENCH ALTERNATIVE ENERGIES AND ATOMIC ENERGY COMMISSION, IS FINDING NEW WAYS TO USE THEM MORE EFFICIENTLY

TALK LIKE A RADIOCHEMIST

RADIOCHEMISTRY – the chemistry of natural and man-made unstable isotopes

ISOTOPE – variants of a chemical element that have the same number of protons but different numbers of neutrons

RADIOLABELS – the addition of a radioactive isotope to a molecule so that it can be traced and imaged

PROTONS – positively charged subatomic particles found in the nucleus of the atom

NEUTRONS – neutral particles found in the nucleus of the atom

METABOLISM – the chemical processes in cells that break down chemical compounds like food or medicine

When did you last take a tablet? Perhaps, it was when you needed to ease a headache or control an allergy? From time to time, most of us do take tablets, but how often do we think about what happens to them after we have swallowed them? More importantly, how do pharmaceutical companies assess the effects of the drugs they produce and what happens to them when they enter our bodies?

“The impact of synthetic organic molecules on health, life quality and lifestyle is beyond doubt,” says Dr Davide Audisio, of the Frédéric Joliot Institute for Life Sciences,

part of The French Alternative Energies and Atomic Energy Commission (CEA), in France. “It is, therefore, of fundamental importance to detect and quantify the fate of organic compounds and provide a precise risk/benefit assessment, before they reach the market and large public exposure.”

Davide is a radiochemist whose work is evidence of the positive and profound impact the science behind radioactive materials can have on our lives. He is working on the FASTLabEX project, making molecules that contain radiolabels so that they can be traced

– and so pharmaceuticals and chemicals can be developed and monitored, and safety ensured. Davide explains, “FASTLabEx will help the pharmaceutical industry to apply the new labelling methods to drugs currently in development in order to provide solutions to the most pressing problems in drug innovation.” But the impact of Davide’s work does not stop there – his project and his expertise as a radiochemist also has applications in crop science and food safety.

RADIOLABELLING

In pharmaceutical compounds, most drugs have what is called an active ingredient. The active ingredient is the molecule that has the desired medicinal effect. However, what happens between swallowing a tablet and the active ingredient entering our bloodstream and reaching its target is very complicated.

This is because the molecules that we take in the tablet can be metabolised by our cells and enzymes – broken down and changed into lots of other different molecules. Hopefully, molecules will be made that have the desired healing effect. However, sometimes other compounds are made that have unwanted side effects.



When new drugs are being designed and tested for safety, Davide and many other researchers will find ways to make radiolabelled versions of the molecules. Because the chemistry in our bodies is so complex, trying to piece together what has happened is very challenging.

However, a radiolabelled compound acts like a GPS for the molecule – we can work out where in the body a molecule has gone and whether it has reacted to form something new.

CARBON-14

The most common form of carbon on earth is carbon-12. Carbon-12 has six protons and six neutrons, giving an overall atomic mass number of 12. Isotopes of carbon, like carbon-14, have the same number of protons as carbon-12 but a different number of neutrons. When it comes to their chemistry, carbon-12 and carbon-14 are very alike. They will react in similar ways and can be used to make the same molecules. The key difference is that carbon-14 is radioactive and, with time, will emit radiation. This radiation can be used to track what happens with the particular element it came from. If a drug is synthesised with a radiolabel like carbon-14, researchers like Davide can follow how that drug is distributed inside a patient's body or, in agrochemical contexts, in the environment.

THE CHALLENGES

Although radiochemistry is a powerful tool for understanding how medicines work, it can be very challenging to make radiolabelled compounds. In the natural world, carbon-14 is a trillion times less common than carbon-12. That means the probability of finding carbon-14 in the pharmaceutical molecule of interest naturally is nearly zero.

Fortunately for radiochemists like Davide, carbon-14 can be made. Nuclear reactors are not just for energy but can also be used to produce the radioisotopes we use for medical imaging as well.

This makes carbon-14 a very expensive element to use and so Davide needs to be very efficient and effective in how he makes molecules containing his radiotracer. As part of the EU-funded project, FASTLabEx, he is working on new strategies to add radiolabels to molecules.

A FAST STRATEGY

Normally, to synthesise a molecule with a radiolabel, the carbon-14 source would be included at the beginning of the process, which is very inefficient and generates radioactive waste. What Davide is trying to do is to add the radiolabel to a molecule that has already been made – using a phenomenon called 'carbon isotope exchange'.

Carbon is not the only element with isotopes. Hydrogen also has several, including deuterium and tritium. Tritium is much more common than carbon-14 and one way to radiolabel compounds with tritium is to shake the molecule in T₂ – a molecule hydrogen gas where both hydrogens have been replaced with tritium, in presence of a catalyst. The tritium in the heavy hydrogen will then exchange with the hydrogens on the molecule, making the radiolabelled version.

Unfortunately, swapping carbon-12 for carbon-14 is not quite so straightforward. Davide's idea is to take carbon-carbon bonds in a finished molecule and come up with new ways to break that one bond and swap a



DR DAVIDE AUDISIO

Research Scientist,
Frédéric Joliot Institute for Life Sciences
The French Alternative Energies and
Atomic Energy Commission (CEA)
France

FIELD OF RESEARCH

Radiochemistry

RESEARCH PROJECT

Developing FASTLabEx, a novel
technique to synthesise radiolabelled
molecules

FUNDER

The European Union

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864576*

carbon-12 for a carbon-14. While this might sound easy, targeting the right bonds and doing this in a single step needs some highly sophisticated chemistry tricks.

If Davide and his colleagues are able to overcome this, the potential impact of FASTLabEx is huge. It would mean radiolabelled compounds could be made in a day, rather than weeks or months. With current methods, it costs 25 000 Euros for less than a gram of radiolabelled carbon dioxide. In addition, a lot of the carbon-14 is lost in the complex, multi-step synthesis, producing radioactive waste along the way.

Radiochemists like Davide play a very important role in helping medicinal chemists design and develop effective medicines. They also help produce other radioisotopes of elements like iodine, which are used to treat many thyroid disorders. Davide's project will also help chemists all over the world learn new ways to make and break very specific carbon bonds, meaning even more exciting molecules can be made.

ABOUT RADIOCHEMISTRY

Radiochemistry is the study of radioactive materials. Most of the elements in the periodic table have several isotopes and many of these are radioactive. Radiochemists work with those isotopes in a variety of different ways.

Some radiochemists, like Davide, are working to synthesise molecules with radioactive isotopes in them. While this is similar in some ways to the job of a synthetic chemist in a pharmaceutical company or university, these molecules are much more complicated to work with and radiochemists need to be trained in how to handle radioactive materials.

Other researchers work with archaeologists or oceanographers who use the information from radioisotopes to age objects and track how the ocean moves. Their work differs to Davide's as they measure the radioactivity but do not need to do chemistry with the radioelement. Some may work in hospitals,

using different isotopes to help treat patients, and some may work at nuclear reactors, helping to find safe ways to deal with waste or make new isotopes.

Radiochemistry is a diverse field and many other professions rely on the knowledge and skills of radiochemists to support their work.

WHAT DOES DAVIDE FIND MOST FASCINATING/REWARDING ABOUT CHEMISTRY?

"The ability to construct organic molecules by breaking and creating new bonds is a very charming concept to me. The idea of being able to imitate nature is fascinating. For me, the most rewarding thing about chemistry is the teamwork involved. I have the privilege of working with a very talented group of people. Interacting with my colleagues is very enriching and constructive. I love when we find new ideas and solutions over these discussions."

WHAT ISSUES WILL BE FACING THE NEXT GENERATION OF CHEMISTS?

"The next generation of chemists will have to face a series of challenges. In organic chemistry, there are still plenty of unsolved fundamental problems. In particular, they will need to find new solutions for making chemicals that will be environmentally friendly – they will need to harness 'green chemistry'."

DOES THE FRÉDÉRIC JOLIOT INSTITUTE FOR LIFE SCIENCES OFFER ANY PUBLIC OUTREACH SCHEMES?

"One of our duties at CEA is to teach our expertise to young people and so we regularly have internship programmes with students. These can vary in format: programme lengths range from a short period of two weeks for high school students, to 6 months for master's students."

EXPLORE A CAREER IN RADIOCHEMISTRY

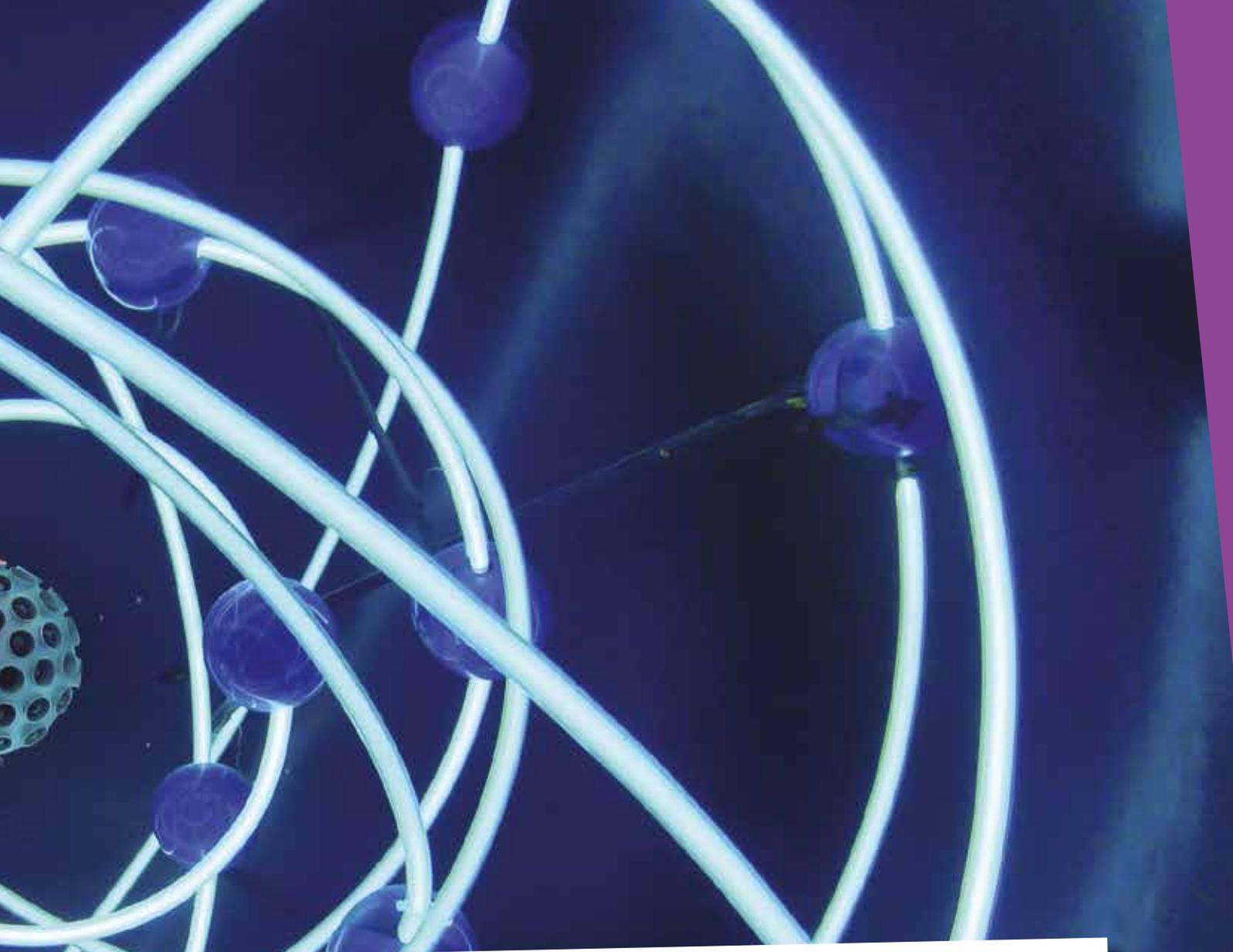
- Radiochemistry and nuclear chemistry are closely related. While direct work experience in radiochemistry may be difficult to get, you may be able to visit the nuclear medicine department of your local hospital or your local university.
- According to [payscale.com](https://www.payscale.com), the average salary for a radiochemist in the UK is £37,000.
- According to [salarylist.com](https://www.salarylist.com), the average salary for a radiochemist in the US is around \$62,000.

PATHWAY FROM SCHOOL TO RADIOCHEMIST

- Most radiochemists will have a bachelor's degree in chemistry or physics, with some having a degree in engineering. Having a relevant master's and PhD may also be useful. As the worldwide demand for radioisotopes increases, radiochemistry is likely to be an in-demand area in the future.
- Radiochemistry is often not extensively covered during a bachelor's degree but a strong background in chemistry, maths and physics will help.
 - Research experience, even in a different field, may be useful for many jobs in radiochemistry, as well as strong laboratory and data analysis skills. A good understanding of safety procedures is mandatory!



Purification of molecules from the reaction mixtures is a fundamental step in organic chemistry and radiolabelling. Davide is purifying a stable carbon-13 labelled compound by column chromatography. Credit: L. Godart/CEA



HOW DID DAVIDE BECOME A RADIOCHEMIST?

WHO OR WHAT INSPIRED YOU TO BECOME A SCIENTIST?

When I was young, I said that I wanted to be a scientist, without really understanding the implications of what that meant! My father was trained as a chemist and this probably influenced me more than I realised. I have been blessed with excellent supervisors during my studies and work, who have played a major role for me, and have been and still are an invaluable source of inspiration.

WHAT WERE YOUR INTERESTS AS A CHILD?

I was very passionate about sports. Soccer and basketball were two of my favourites. At school, I was always more interested in scientific topics.

WHAT ATTRIBUTES HAVE MADE YOU SUCCESSFUL AS A SCIENTIST?

Passion, curiosity and motivation.

HOW DO YOU OVERCOME OBSTACLES IN YOUR WORK?

I try to stay focused and think outside of the box. Interaction and discussion with my colleagues can be very helpful, as well.

WHAT ARE YOUR PROUDEST CAREER ACHIEVEMENTS?

My proudest career achievements are related to the impact I might have on my students. To see them grow and mature as scientists over the time they spend with us and help them shape their future careers is highly rewarding.

DAVIDE'S TOP TIPS

- 01** Take advantage of opportunities to see new things, including exchange programmes. Having the opportunity to see new laboratories or countries can be really enriching and help broaden your horizons.
- 02** Talk about your scientific problems with others – this can be an excellent way of gaining new insights and figuring things out.
- 03** Do what you are most passionate about. Follow your own path.

WHY DO SOME CHEMICAL REACTIONS OSCILLATE?

A CHANCE DISCOVERY OF AN UNUSUAL OSCILLATORY REACTION BY A RUSSIAN CHEMIST NEARLY 70 YEARS AGO HAS PAVED THE WAY FOR SOME POTENTIALLY EXCITING, MODERN APPLICATIONS. PROFESSOR IRVING EPSTEIN AT BRANDEIS UNIVERSITY, USA, IS INVESTIGATING THE MYSTERIES BEHIND THIS VERY SPECIAL CHEMICAL REACTION

TALK LIKE A CHEMIST

LINEAR PROCESS – a process in which the observed value is linearly proportional to the input variable

NONLINEAR PROCESS – a process in which the observed value is not linearly scaled to the input variable

VARIABLE – a quantity that can take on different values at different times or positions

OBSERVABLE – what you measure or see in a process

OSCILLATION – a periodic change, like the tides in the sea or the motion of a pendulum

CHAOS – non-periodic, deterministic change, like the weather

Sometimes life is simple. You push an object, it moves. You push the same object twice as hard; it moves twice as fast. If you were to record the forces and speeds in an experiment, you would expect to see that the greater the force on the object, the faster it moves. If the speed of the object always increases in direct proportion to the force on it, this is known as a linear relationship.

However, as Professor Irving Epstein and his team at Brandeis University in the US have shown, not everything is that simple – particularly in chemistry. Irv heads the Nonlinear Chemical Dynamics Group which investigates systems that show much more complex, nonlinear behaviour.

So, what does it mean when a process is nonlinear? In a linear process, the outcome is linearly proportional to the input variable. Let's take the earlier example: If you pushed a box with twice as much force and the speed doubled, and then with four times as much force, and the speed quadrupled, this would be an example of a linear process. If you think of this process in terms of a graph, plotting a graph of input force against output speed would produce a straight line. But if, when you

doubled the amount of force used, the speed increased by four times the amount, this would be an example of a nonlinear process. The ratio of speed to force is not constant, producing a nonlinear relationship, and plotting a graph of output speed against input force would produce a curve.

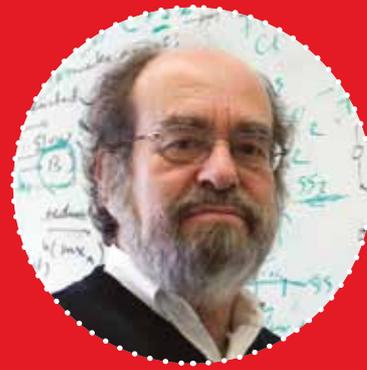
Nonlinear systems can be challenging to understand and sometimes show some unusual phenomena, including oscillatory behaviour of the observable process. Irv explains, "Common examples of nonlinearity beyond chemistry are population oscillations in a predator-prey system, like foxes and rabbits; the apparently (but not truly) random times at which a drop of water falls from a dripping faucet; the growth of the striped pattern on a tiger's coat; the fractal structure of a snowflake." While these phenomena are familiar to us, the nonlinear processes responsible for them are in fact difficult to predict and understand.

HOW DOES NONLINEARITY RELATE TO CHEMISTRY?

Oscillatory reactions are an example of nonlinear processes that occur in chemistry. These were originally discovered by accident by a Russian scientist called Boris Belousov in



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PROFESSOR IRVING EPSTEIN

Henry F. Fischbach
Professor of Chemistry
Brandeis University, USA

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FIELD OF RESEARCH

Chemistry

.....

RESEARCH PROJECT

Understanding nonlinear dynamics in
chemical systems

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FUNDERS

National Science Foundation, W.M. Keck
Foundation, Army Research Office,
DARPA, Howard Hughes Medical
Institute (for science education efforts)

the 1950s. “Belousov was actually looking for something else,” says Irv. “While conducting his experiment, he happened to notice that the concentration of yellow ceric ions in his reaction mixture periodically increased and decreased.” In the reaction, there were yellow-coloured ceric ions that could be converted to colourless cerous ions. The overall colour of the reaction mixture oscillated with time, as the concentration of ceric ions increased and decreased periodically.

The chemistry community was highly sceptical of Belousov’s discovery, considering his results to be impossible. This was because of a mistaken belief that chemical oscillation violates the second law of thermodynamics, which dictates that the entropy of the universe must always increase. However, Belousov passed his experimental notes to another Russian chemist, Simon Shnoll, who set his young PhD student, Anatol Zhabotinsky, to work on the problem.

Zhabotinsky was fascinated. Not only was he able to reproduce Belousov’s work, but he brought the idea of oscillatory reactions to the attention of the chemistry community in a more convincing fashion. Now, nearly 70 years later, Irv and his team are building on these findings and are investigating ways to deliberately design chemical oscillators that have certain properties.

CHEMICAL OSCILLATORS

The reaction discovered by Belousov and developed by Zhabotinsky is known as the Belousov-Zhabotinsky reaction. Oscillatory reactions have many exciting potential applications, from drug delivery to the analysis of chemical processes. Interestingly, they may even explain some of the earliest reactions that took place on Earth to produce life.

For chemical reactions where concentrations are constantly changing, the trick is to find patterns, like periodic oscillation, in the behaviour of the reaction. Similar periodic and patterned processes can be found in embryos that grow into organisms, or stalactites and stalagmites that develop in caves.

Irv and the Nonlinear Dynamics Group have made several new chemical oscillators and shown that coupled oscillators can be chimeric in their behaviour. In a coupled system, all the oscillators interact, but in some systems, not all of them show the same behaviour. In chimeric systems, some oscillators behave periodically, whereas others deviate from this and behave chaotically. It may seem like a giant leap in our understanding of the world around us, but Irv believes that oscillatory reactions can provide insight into natural, evolutionary phenomena. “For instance, we

may be able to explain why some organisms, like dolphins, can have half their brain in a sleep state while the other half remains alert to guard against predators.”

In an example of some eye-catching chemistry, Irv has used colourless gels as a medium for the Belousov-Zhabotinsky reaction to make a chemical reaction ‘dance’ when you shine light on it. During the reaction, the catalyst gains or loses electrons, triggering a polymer to change size and move, producing coloured waves in the gel.

Nonlinear chemical dynamics is a complex field, but chemists like Irv are uncovering the equations and physics to help us understand and model such reactions. Without this understanding, we would be unable to design chemical systems that behave as oscillators and have properties with useful applications. One example could be to use this fundamental knowledge to make systems that move toward or away from a source of light. All of this work gives us new insights into the rich and varied behaviour of chemical systems.

ABOUT CHEMISTRY

Chemistry is about understanding how atoms and molecules interact and react. This knowledge can be used for a wealth of applications, from designing and making new molecules to learning more about fundamental science. By studying new reactions and discovering new molecules, chemists might be able to find molecules with anti-cancer properties, for example, or for use in television displays. "These are exciting times for chemistry," says Irv. "Many of the world's most pressing issues – health, energy, climate change, water and food production – require a deep understanding of chemistry."

Of course, investigations like those undertaken in Irv's Nonlinear Chemical Dynamics Group take time, and many reactions will fail, but chemistry is a varied field and the possibilities are endless! Not all chemists wear white coats and mix chemicals in flasks. A whole range of research projects are carried out by Irv's team. Of course, many of these research projects do

involve conducting experiments, but some are purely theoretical and computational, "like developing and simulating a model for the behaviour of a set of coupled chemical oscillators," explains Irv.

"Serendipity has played a significant role in this field," says Irv. "Important phenomena are often discovered while looking for something else." Belousov's discovery of oscillatory reactions is a prime example of this and highlights why keeping an open mind is so important for any scientist.

CAREERS IN CHEMISTRY

According to the US Bureau of Labor Statistics Occupational Outlook Handbook for 2019, "Overall employment of chemists and materials scientists is projected to grow 5 per cent from 2019 to 2029, faster than the average for all occupations. Chemists and materials scientists who have an advanced degree, particularly a PhD, are expected to have the best opportunities." So, there

are many excellent career opportunities in this field.

Most chemists will work in laboratories or in research teams, where teamwork and collaboration are key skills. "A modern research group is a diverse, multigenerational community of people from all over the world," says Irv. "At any given time, our group might comprise undergraduates, graduate students, postdoctoral fellows, visiting professors, and even the occasional high school student."

"I would recommend chemistry as a career to anyone who is fascinated by trying to understand the ways in which atoms and molecules, objects far too small for us to see, interact to produce the macroscopic world in which we live," Irv continues. "If you enjoy solving these sorts of puzzles and would like to get paid to do this, you should certainly consider a career in chemistry."

EXPLORE A CAREER IN CHEMISTRY

The American Chemical Society has lots of useful information on careers in chemistry as well as educational resources:

<https://www.acs.org/content/acs/en/careers.html>

Similarly, the Royal Society of Chemistry has resources to help you with your studies and read about future job options for chemists:

<https://edu.rsc.org/student>

Irv's Nonlinear Chemical Dynamics Group welcomes graduate students and undergraduates (and an occasional high school student) to the lab. Contact research groups near you and ask them whether they will provide a tour or come into your school/college.

Search the internet for 'chemistry apprenticeships' and there could be opportunities that suit you. For example, EDF Energy (https://careers.edfenergy.com/content/Chemistry-Apprenticeship/?locale=en_GB) and Nordmann (<https://www.nordmann.global/en/career-with-nordmann/training-programs-apprenticeship-studies>) offer chemistry apprenticeships.

According to the US Bureau of Labour Statistics, the average salary for a chemist is \$77,600.

PATHWAY FROM SCHOOL TO CHEMISTRY

Irv recommends taking classes in maths, physics and biology at school, as well as studying chemistry. Most universities will offer degrees in chemistry and, to become a research chemist, a degree will be followed by a Master's degree and/or PhD. As researchers, chemists often specialise in sub-disciplines of chemistry, such as physical, organic or inorganic chemistry, or focus on even more specific topics.



Boris Belousov, the Russian scientist who discovered an unusual oscillatory reaction in the 1950s.



Russian chemist Anatol Zhabotinsky expanded upon Belousov's work and brought the idea of oscillatory reactions to the attention of the chemistry community.



HOW DID IRV BECOME A CHEMIST?

DID YOU KNOW YOU WANTED TO BE A CHEMIST WHEN YOU WERE YOUNGER?

I always knew I was interested in maths and science. I didn't decide on chemistry until my first year at university.

WHO OR WHAT INSPIRED YOU TO GET INTO CHEMISTRY?

My high school had a very good chemistry programme and an outstanding chemistry teacher, Miss Butler. Then, my first college chemistry course was taught by William Lipscomb, who later won the Nobel Prize in Chemistry. I think I also just liked mixing things together and seeing colours change or flames appear!

IS THERE A CHEMIST WHO YOU PARTICULARLY ADMIRE?

William Lipscomb was not only a brilliant chemist, but a wonderful person, who provided wise counsel and unflagging support for his students. He received the Nobel Prize for his work on inorganic boron chemistry, then turned to unravelling the structures of biologically important proteins, where again he made major contributions. As well as being a chemist, he was also

a concert-level clarinetist and an avid tennis player!

ARE THERE ANY EXPERIMENTS YOU WISH YOU COULD DO BUT CAN'T FOR ONE REASON OR ANOTHER?

The oscillating reactions we study tend to have periods of a few seconds to a few hours. I wish we had the tools to find and manipulate oscillations at much shorter time scales. Similarly, it would be nice to be able to study pattern formation at the nanoscale.

YOUR GROUP HAS PUBLISHED HUNDREDS OF PAPERS OVER PAST DECADES. OF ALL THESE ACHIEVEMENTS, IN WHICH DO YOU TAKE THE GREATEST PRIDE?

The discovery of the first deliberately designed oscillating reaction remains the high point for me. This is in part because our proposal to undertake the project was turned down three times by a sceptical National Science Foundation before they agreed to fund it, and then, once we began it, our idea worked within a month.

WHAT DO YOU KNOW NOW THAT YOU WISH YOU'D KNOWN WHEN

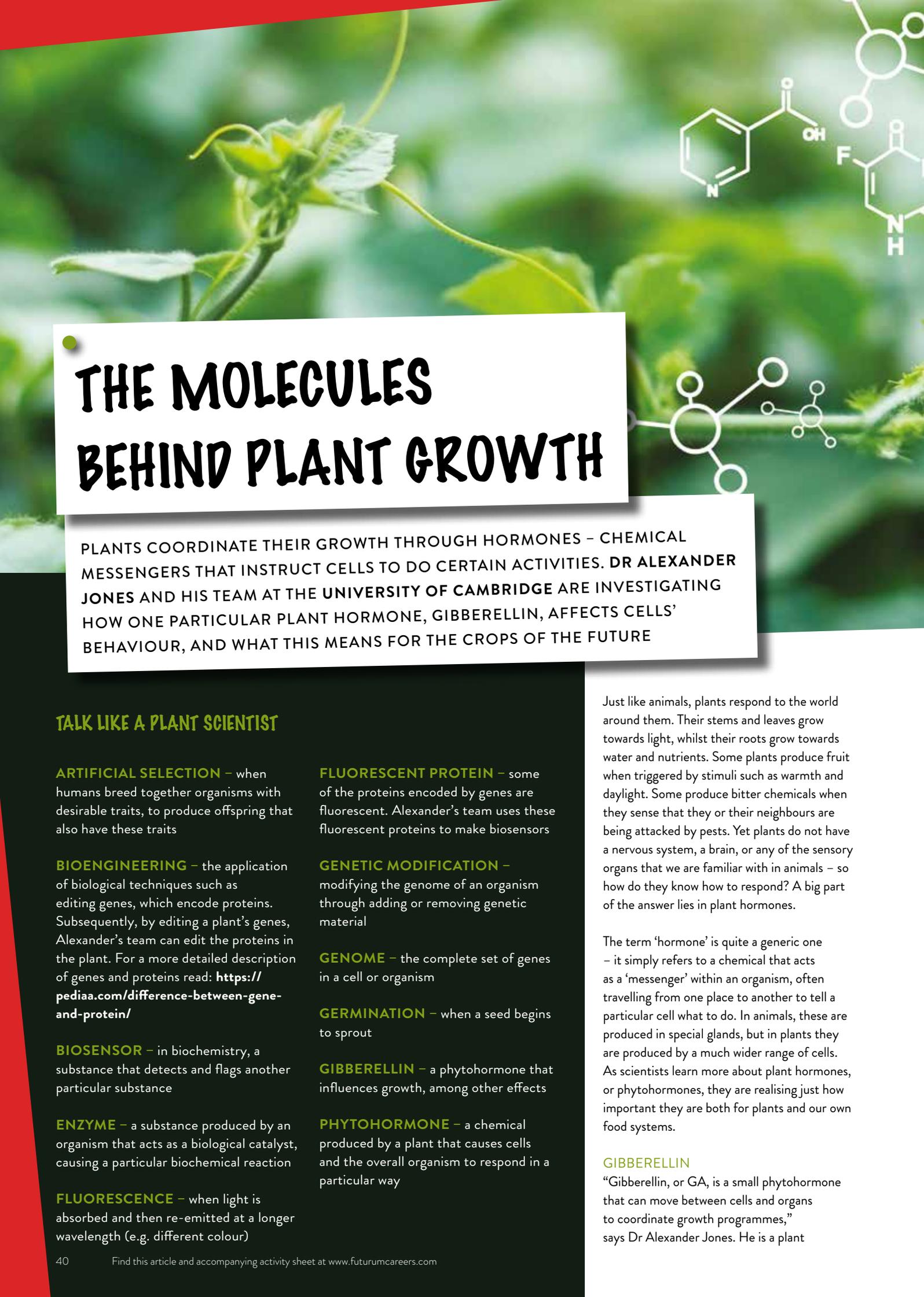
YOU WERE YOUNGER?

There are two things. The first is that persistence, resilience and hard work (as well as a good dose of luck) count for at least as much as natural intelligence. The second is that starting off in one career direction does not determine one's destiny. Change is always possible, and often desirable.

IRV'S TOP TIPS

01 Try to figure out what you enjoy doing and what you're good at. Then, look for a career that puts you within the intersection of these domains.

02 "Chance favours the prepared mind" is not just a motto for nonlinear chemical dynamics, but also for thinking about future careers. It never hurts to think about your career options and plan in advance.



THE MOLECULES BEHIND PLANT GROWTH

PLANTS COORDINATE THEIR GROWTH THROUGH HORMONES – CHEMICAL MESSENGERS THAT INSTRUCT CELLS TO DO CERTAIN ACTIVITIES. DR ALEXANDER JONES AND HIS TEAM AT THE UNIVERSITY OF CAMBRIDGE ARE INVESTIGATING HOW ONE PARTICULAR PLANT HORMONE, GIBBERELLIN, AFFECTS CELLS' BEHAVIOUR, AND WHAT THIS MEANS FOR THE CROPS OF THE FUTURE

TALK LIKE A PLANT SCIENTIST

ARTIFICIAL SELECTION – when humans breed together organisms with desirable traits, to produce offspring that also have these traits

BIOENGINEERING – the application of biological techniques such as editing genes, which encode proteins. Subsequently, by editing a plant's genes, Alexander's team can edit the proteins in the plant. For a more detailed description of genes and proteins read: <https://pediiaa.com/difference-between-gene-and-protein/>

BIOSENSOR – in biochemistry, a substance that detects and flags another particular substance

ENZYME – a substance produced by an organism that acts as a biological catalyst, causing a particular biochemical reaction

FLUORESCENCE – when light is absorbed and then re-emitted at a longer wavelength (e.g. different colour)

FLUORESCENT PROTEIN – some of the proteins encoded by genes are fluorescent. Alexander's team uses these fluorescent proteins to make biosensors

GENETIC MODIFICATION – modifying the genome of an organism through adding or removing genetic material

GENOME – the complete set of genes in a cell or organism

GERMINATION – when a seed begins to sprout

GIBBERELLIN – a phytohormone that influences growth, among other effects

PHYTOHORMONE – a chemical produced by a plant that causes cells and the overall organism to respond in a particular way

Just like animals, plants respond to the world around them. Their stems and leaves grow towards light, whilst their roots grow towards water and nutrients. Some plants produce fruit when triggered by stimuli such as warmth and daylight. Some produce bitter chemicals when they sense that they or their neighbours are being attacked by pests. Yet plants do not have a nervous system, a brain, or any of the sensory organs that we are familiar with in animals – so how do they know how to respond? A big part of the answer lies in plant hormones.

The term 'hormone' is quite a generic one – it simply refers to a chemical that acts as a 'messenger' within an organism, often travelling from one place to another to tell a particular cell what to do. In animals, these are produced in special glands, but in plants they are produced by a much wider range of cells. As scientists learn more about plant hormones, or phytohormones, they are realising just how important they are both for plants and our own food systems.

GIBBERELLIN

"Gibberellin, or GA, is a small phytohormone that can move between cells and organs to coordinate growth programmes," says Dr Alexander Jones. He is a plant



scientist in the University of Cambridge's Sainsbury Laboratory, where he heads up an interdisciplinary team of researchers investigating exactly what GA does within plants. "The first thing GA does in a cell is bind to a receptor protein, which triggers a cascade of signals that ultimately affects gene expression."

GA is essential for plants to grow properly, but there is still much that is not yet understood about how it functions or what it regulates exactly. It is known that GA can lead to cells elongating and cells dividing, both mechanisms by which plants grow. GA also plays a part in seed germination, flowering and fruit development – all highly complex processes. Uncovering the pathways behind these processes is what Alexander's team is working on.

FINDING THE PATH

Chemical signalling involves an initial 'cue', an ensuing pathway of reactions and, ultimately, a response from the organism. For instance, GA production can be triggered by cues like decreased light, increased temperature or salt stress. GA levels also fluctuate depending on internal cues, such as the stage at which the plant is in its lifecycle. Once GA accumulates to a certain level, it can trigger growth programmes. "The exact nature of the growth that follows depends on the plant tissue and the timing," says Alexander. "For instance, GA can trigger the production of enzymes that loosen cell walls, allowing the plant cells to expand. Or near the beginning of a plant's lifecycle, it can trigger enzymes that release nutrients that stimulate seed germination."

Phytohormones come in a wide range of shapes and sizes. Because the same chemical can provoke very different responses depending on other conditions, it can be difficult to categorise them by function, and GA is no

exception. There is still plenty to discover about how GA functions, in the different parts of a plant and at different times, and how it interacts with other biochemical processes.

PROTEIN ENGINEERING

To be able to tell when and how these pathways are taking place, plant scientists have invented some clever techniques to flag when certain chemicals are present. Scientists can modify plant genomes so they express a special protein that can be easily detected, such as one that lights up or fluoresces differently when it binds to the chemical of interest – the latter of which is exactly what Alexander's team has created.

Alexander has developed a new biosensor called the Gibberellin Perception Sensor (GPS), which allows his team to tell when GA is being made and in what quantities. "GPS is a direct biosensor, meaning it binds directly to GA," Alexander says. "It's based on fluorescence, which means it changes the colours of light it emits when it binds. Fluorescence can be tracked with exquisite resolution." The biosensor is coded for by a single gene, meaning it can be inserted into a plant's genome where it will be produced naturally in every cell. The team can then use powerful microscopes to see where GA is being produced and where it travels to.

FINDINGS AND APPLICATIONS

"The first findings of a project like this can often be the most important," says Alexander. "With a biosensor, you can see something nobody has ever seen before." For example, the team has found gradients of GA within growing roots and shoots, and is now learning about why these gradients are important for the plant.

Modifications to GA levels in plants have already led to huge benefits for society. In the 1950s and 60s, concerns about possible mass starvations led to scientists finding new



DR ALEXANDER JONES

Research Group Leader
Sainsbury Laboratory
University of Cambridge, UK

FIELD OF RESEARCH

Plant Science and Bioengineering

RESEARCH PROJECT

Investigating how and why the plant growth hormone gibberellin is distributed across cell types

FUNDERS

This work has received funding from the Gatsby Charitable Foundation under a Gatsby Research Fellowship and from the ERC under the European Union's Horizon 2020 research and innovation programme (grant agreement n° 759282)

techniques to boost agricultural productivity – an effort known as the Green Revolution. One key way they achieved this was through breeding crops to be shorter, so they would put more of their energy towards growing edible grains that were less likely to be damaged by wind. This process involved artificially selecting plants that either made less GA or responded abnormally to GA, so the hormone did not lead to the normal growth effect.

"GA manipulations are already wildly successful in agriculture, but there are sometimes unwanted side-effects" says Alexander. For instance, one study* saw scientists genetically modify rice plants to express lower GA, but found that although modified plants were shorter, they also did not develop rice grains correctly, since GA is linked to both shoot elongation and reproductive development. As Alexander says, "We need a deeper understanding of how GA works so we can fine-tune these modifications to work for us."

*<https://pubmed.ncbi.nlm.nih.gov/12858182/>

MEET THE TEAM

Alexander's research group includes people from a wide range of academic backgrounds, which ensures that the relevant expertise is present at every stage of the project. Below, two team members share their insights.

BIJUN TANG, PHD STUDENT



WHAT IS YOUR ROLE IN ALEXANDER'S RESEARCH GROUP?

My role in this project is to focus on re-engineering and improving the GPS biosensor. This sensor detects GA concentrations, so gives us an insight into GA distribution in plants and how concentrations change during plant growth.

CAN YOU DESCRIBE THESE BIOENGINEERING ACTIVITIES?

One issue with our biosensor is that it is not reversible – once it binds to the GA, it cannot be released easily. This means we can only detect increases in concentration, but not decreases. We are trying to engineer the sensor to allow the bound GA to be released easily, while maintaining its ability to bind easily in the first place.

HOW DOES YOUR KNOWLEDGE OF BIOCHEMISTRY AND MOLECULAR BIOLOGY HELP IN YOUR WORK?

Biochemistry involves investigating the structures and functions of proteins. The sensor we made is essentially one protein formed from four different

proteins, so having biochemical knowledge helps me improve the sensor's function by investigating its structure.

YOUR PHD IS IN BIOCHEMISTRY BUT YOU STUDIED NATURAL SCIENCES.

During my undergraduate degree in natural sciences, I learned the foundations of many different aspects of biology through lectures and practical classes. I realised that understanding proteins was what interested me the most, which led me to a PhD in biochemistry.

My father is a professor of chemistry in my hometown of Shenzhen in China. He has always been a role model for me, and demonstrated enthusiasm and passion about science.

WHAT DO YOU HOPE TO DO AFTER YOU COMPLETE YOUR PHD?

My research experience has been great so far and making new discoveries excites me every day. After finishing my PhD, I would like to develop more powerful molecular tools and use them to understand cellular events in plants. My goal is to improve the quality of crops, so they are resistant to environmental stress.

WHAT DO YOU LIKE TO DO OUTSIDE OF WORK?

I like to play table tennis. I was captain of my university's women's team when I was an undergraduate and we played many regional and national matches. During lockdown, I transferred my interests to painting, and playing the flute and piano

DR ANNALISA RIZZA, RESEARCH ASSOCIATE



WHAT IS YOUR ROLE IN ALEXANDER'S RESEARCH GROUP?

My role in this project is to understand how and why GA is distributed through the plant. I

look at GA in two zones in plant roots: the tip, known as the division zone, and the intermediate part, called the elongation zone. I found that the cells in the division zone contain less GA than in the elongation zone, getting us closer to understanding how GA distribution influences root growth.

WHICH PLANTS DO YOU STUDY?

We use *Arabidopsis thaliana*, a small flowering plant used as a model organism by many plant scientists. It is quick and easy to grow, produces a lot of seeds and has a small genome that makes its genetic functions easy to study. It is also easy to insert new genes

into its genome, to investigate the effect they have on plant function or to introduce our biosensors as research tools.

HOW DOES THE GPS BIOSENSOR WORK?

We genetically modify *Arabidopsis* plants to express the GPS biosensor, a relatively easy process that only involves the insertion of one gene. When GPS binds to GA, it changes shape and emits a certain sort of fluorescence. We can then use a fluorescence microscope to detect where GA is being expressed in the plant and in what quantities.

WHAT DO YOU ENJOY ABOUT YOUR WORK?

I am a curious person and love discovering new things. My work feeds my curiosity and I can do different experiments every day to answer biological questions.

DID YOU ALWAYS WANT TO STUDY PLANTS?

At the beginning of my career, I wanted to become a medical doctor, but changed my mind after seeing a frog get dissected. I believe that not sticking to my original plan was a good choice for me. My advice is that it is excellent if you are strongly committed to one particular career goal, but if you do not have this goal, be open to big changes early in your career path.



EXPLORE A CAREER IN PLANT SCIENCE

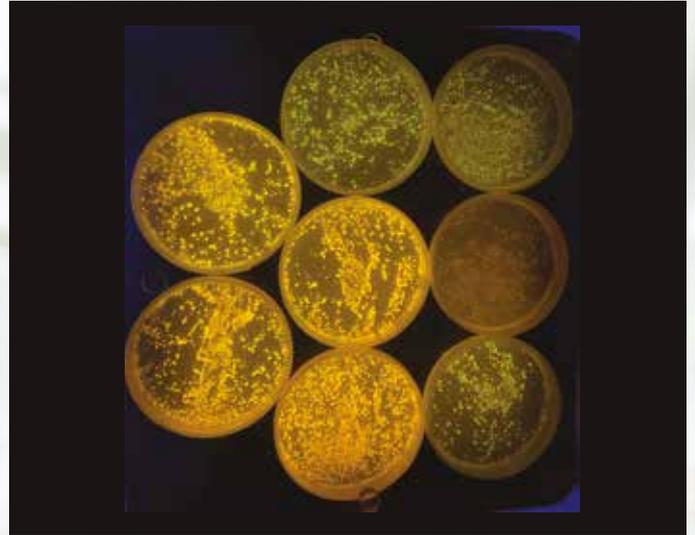
- Plant science (sometimes referred to as botany) can draw on many different biological disciplines, such as biochemistry, molecular biology, genetics and ecology. Degrees in biology, natural sciences and related disciplines can all lead to a career in plant science.
- There are many outreach schemes that introduce secondary school students to the world of plant sciences. For instance, the Sainsbury Laboratory runs the Gatsby Plant Science Education Programme, which supports curriculums and runs bioscience summer schools.
- The average molecular and cellular biologist salary in the UK is £37,000.

ALEXANDER'S TOP TIP

Bioengineering is a fun and dynamic discipline with plenty of distractions. I recommend focusing on a specific field to build expertise, rather than spreading your interests too thinly.

PATHWAY FROM SCHOOL TO PLANT SCIENCE

Undergraduate degrees in biology generally require qualifications in at least two science subjects and maths. Alexander recommends a foundation in maths and computer programming for any scientist. Once at university, he says that courses involving biochemistry, signalling and structural biology are all very useful.



Here, the Gibberellin Perception Sensor (GPS) is expressed in yeast colonies.

HOW DID ALEXANDER BECOME A PLANT SCIENTIST?

WHAT DID YOU WANT TO BE WHILE GROWING UP?

I have always wanted to become a biologist of some sort. I love studying living things.

HAVE YOU ALWAYS BEEN FASCINATED BY PLANTS?

Yes, I have. They are fundamental to our existence and yet we understand so little about them. Plants 'think' differently to humans and thrive with entirely different strategies for life. There is a subtle beauty in the logic of plants.

IS THERE A BOTANIST YOU PARTICULARLY ADMIRE?

John Stevens Henslow, Darwin's mentor, was a botanist. The old school of botany spent

their time carefully observing plant traits and drawing insights from them. Scientific tools have dramatically changed since then, but I admire their attention to detail and their love of knowledge.

WHAT ASPECT OF YOUR WORK EXCITES YOU THE MOST?

Inventing new technologies and discovering new information about plants are equally exciting. Often, they go hand in hand, with some years in between.

WHAT TRAITS DO YOU FIND USEFUL AS A SCIENTIST?

Perseverance is an important trait in all science, but particularly in plant science where so much patience is required. Creativity

and the courage to act on new ideas despite the risk of failure are also very valuable.

WHAT DO YOU WISH YOU HAD KNOWN WHEN YOU WERE YOUNGER?

How important teamwork is to science, and to ask for advice from senior mentors early and often. You are not expected to know everything at any point, and certainly not at the start of your career!

WHAT WAS YOUR FAVOURITE BOOK AS A TEENAGER?

I liked fantasy books, wizards and rings and such. "Any sufficiently advanced technology is indistinguishable from magic," as Arthur C Clarke said!

BUILDING BONES USING STEM CELLS AND GENE THERAPY

DR PASCALE V GUILLOT IS BASED AT THE UNIVERSITY COLLEGE LONDON ELIZABETH GARRETT ANDERSON INSTITUTE FOR WOMEN'S HEALTH. SHE IS LEADING A TEAM OF CELL BIOLOGISTS WHO ARE USING HUMAN STEM CELLS TO GROW BOTH HEALTHY AND BRITTLE BONE TISSUE IN THE LAB. WHY? SO THEY CAN INVESTIGATE THE CAUSES OF A BRITTLE BONE DISEASE CALLED OSTEOGENESIS IMPERFECTA AND DEVELOP INNOVATIVE TREATMENTS TO MAKE BONES STRONGER

TALK LIKE A CELL BIOLOGIST

COLLAGEN – a major structural protein in the body, found in skin, bones and connective tissues. Type I collagen is the main component of bones

CRISPR – a genetic engineering tool that involves cutting and inserting genetic material in the DNA

EPITHELIAL CELLS – a specialised type of cell that lines the surface of organs, typically acting as a protective barrier

GENE THERAPY – modifying a person's genes to treat or cure disease

IN VITRO – a process taking place in the lab (e.g. in a test tube); the opposite of *in vivo* (in a living organism)

OSTEOBLAST – a specialist type of cell that produces a bone matrix. Bone is not uniformly solid but consists of a flexible matrix (about 30%) and bound minerals (about 70%) that are intricately woven and endlessly remodelled by osteoblasts and

osteoclasts. To read more about this, visit: <https://en.m.wikipedia.org/wiki/Bone>

OSTEOCLAST – a specialist type of cell that resorbs the old bone matrix

OSTEOGENESIS IMPERFECTA – also known as brittle bone disease, osteogenesis imperfecta is a rare genetic disease that starts in the womb and leads to deformities of the skeleton and breaking bones (fractures)

PLURIPOTENT – used to describe stem cells that can create all the different cell types present in the body, but are not totipotent (i.e. cannot create the placenta or umbilical cord)

STEM CELLS – unspecialised cells that are used as the 'raw material' to produce specialised cells

THERAPEUTIC – a therapy or medical treatment

"Our bones are extremely important, not just for supporting our body and protecting our internal organs, but also as a reservoir of minerals and other substances involved in metabolism," says Dr Pascale V Guillot. "It is therefore very important to maintain bone health." Pascale and her team are part of the Elizabeth Garrett Anderson Institute for Women's Health at University College London in the UK. They are performing research involving some truly cutting-edge techniques: growing human bone tissue in the lab, developing stem cell-based therapeutics, reprogramming cells to pluripotency and editing the genetic makeup of stem cells to correct genetic defects.

Bone fragility affects many people for different reasons. Menopause, inactivity or immobility, and even lack of gravity (such as astronauts experience) can all weaken bones. Fragile bones can also be genetic: osteogenesis imperfecta, or brittle bone disease, is a rare inheritable disease that leads to fractures, short stature and skeletal deformities. Pascale and her team are focusing on this disease, but their findings will also help many people with bone fragility.



BONE BIOLOGY

Bones may seem like relatively simple parts of the body, but there is plenty to them that does not initially meet the eye. “Bones are complicated structures, and are constantly remodelling,” says Pascale. “Cells called osteoblasts build new bone tissue, while cells called osteoclasts destroy old bone tissue – ideally at the same rate.” The osteoblasts produce fibres of a protein called type I collagen, which is a major building block within our bodies, contributing to skin, muscles and tendons, as well as bones. Once the osteoblasts have secreted the collagen, they then control the deposition of calcium and other minerals on these fibres, which add strength and structure to our skeleton.

Osteogenesis imperfecta is the result of errors (mutations) in genes that lead to insufficient or abnormal production of collagen fibres in bones. “We originally thought that the faulty fibres were directly responsible for weak bones, but it turns out there is more to it than that,” says Pascale. “Faulty fibres do lead to a weak bone structure – imagine a house made of cardboard bricks. However, these fibres also prevent osteoblasts from maturing properly, meaning they aren’t able to mineralise the fibres. So, as well as the house being made from cardboard, it also has fewer bricks than it should.” Added to this, reduced osteoblast activity also leads to increased osteoclast activity, meaning that bone destruction is happening faster than bone construction. Now Pascale’s team has an understanding of the pathway that leads from genetic mutations to bone fractures, they can move on to tackling osteogenesis imperfecta.

BUILDING BONES IN THE LAB

Pascale’s team is extracting epithelial cells found naturally in samples of people’s urine. Though these cells are already fully specialised, the team use a ground-breaking technique to return them to a pluripotent stem cell state. This cell rejuvenating technique, known as cellular reprogramming to pluripotency (induced pluripotent stem cells, iPSCs), is revolutionising cell biology. Previously, non-pluripotent stem cells (called multipotent stem cells) were mainly isolated from various tissues of healthy donors and grown in the laboratory. However, as they grow, they also start to age and progressively lose their ability to specialise into bone-forming cells (osteoblasts) and repair tissues. Now, cell biologists can derive osteoblasts directly from iPSCs. “The iPSCs we create have the potential to become any type of specialist cell in the body,” says Pascale. “For our research, we cultivate them to become osteoblasts.”

Using these osteoblasts, Pascale’s team is working to build three-dimensional structures made up of human bone *in vitro*. “This technique means we don’t have to experiment using animals, and increases the physiological relevance of our work,” says Pascale. “However, we have several challenges to overcome, namely engineering a system where human cells can thrive and produce a bone matrix.” Bones are complex tissues requiring precise processes to build them correctly, so this is no easy task, but the team is making strong progress.

FROM EXPERIMENTS TO TREATMENTS

“Using urine from healthy patients and osteogenesis imperfecta patients, we’re able to build healthy bone structures and fragile



DR PASCALE V GUILLOT

Associate Professor and Group Head
Elizabeth Garrett Anderson Institute for
Women’s Health
University College London, UK

FIELD OF RESEARCH

Stem Cell Biology

RESEARCH PROJECT

Combining stem cell and gene editing techniques to develop the next generation of treatments for osteogenesis imperfecta

FUNDERS

UK Research and Innovation
Medical Research Council

bone structures,” says Pascale. “We can then test the effects of different treatments on the fragile bone structures, seeing if any stimulate the osteoblasts to mature properly and improve bone strength.” Excitingly, the team is also involved in a clinical trial that will determine the safety and efficacy of prenatal cell therapy for osteogenesis imperfecta.

Since osteogenesis imperfecta is a genetic disease, there is another possible solution: editing the genes themselves to repair the genetic mutation. “Using patients’ cells, we can correct the mutation using CRISPR, and then transplant these corrected cells back into the patients,” says Pascale. This technique has even greater potential than stem cell transplants, since the human body is much more likely to accept its own cells than those from a different person.

When will we see the team’s research in action? As Pascale explains, “The next step is to move from discovery to commercialisation, so these techniques can help individuals with osteogenesis imperfecta – and potentially people with other fragile bone conditions – across the world!”

ABOUT CELL BIOLOGY

Cell biology covers the fundamental units of life: the cells that make up every living organism on the planet. Cell biologists study the structure and function of these cells and how they work together to form whole organs and organisms. Often, discoveries in cell biology have big implications for medicine, so cell biologists will regularly work alongside clinicians, pharmaceutical developers and medical professionals. Pascale explains more about her career.

WHAT DOES THE FUTURE HOLD FOR CELL BIOLOGY?

My team and I are very excited to work with stem cells to generate transformative therapeutic techniques. We are passionate about understanding how donor stem cells work to repair tissue – rather than forming healthy tissue themselves, it looks like

they mainly contribute by releasing sacs of molecules that activate the host's own repair system.

IS THERE A CELL BIOLOGIST YOU PARTICULARLY ADMIRE?

Marie Curie is an excellent role model: a mother, a wife and a pioneering scientist who won two Nobel prizes. She admitted juggling these was a challenge: "I have frequently been questioned, especially by women, how I could reconcile family life with a scientific career. Well, it has not been easy." Yet, Marie Curie maintained the self-belief that led to her breakthroughs: "We must have perseverance and above all confidence in ourselves. We must believe that we are gifted for something and that this thing, at whatever cost, must be attained."

WOULD YOU RECOMMEND A CAREER IN CELL BIOLOGY?

Absolutely. We can make wonderful discoveries, and often work hand-in-hand with clinicians to help develop new treatments and improve people's quality of life, all while increasing our knowledge of the processes underlying how bodies work.

ARE THERE MANY CAREER OPPORTUNITIES FOR CELL BIOLOGISTS IN THE UK?

Yes, cell biology is an international career, including in the UK. We have prestigious universities where academic careers are very possible, as well as world-leading pharmaceutical companies that often take on young people.

EXPLORE A CAREER IN CELL BIOLOGY

- The British Society for Cell Biology (BSCB) has a page dedicated to careers and courses:

<https://bscb.org/learning-resources/softcell-e-learning/careers-and-courses/>

BSCB also offers financial support for high calibre undergraduate students, who wish to gain research experience in cell biology during their summer holidays:

<https://bscb.org/competitions-awardsgrants/studentships/>

- Many academic and research institutions engage with schools, including on the subject of cell biology. For instance, University College London (where Pascale works) regularly partners with The Sutton Trust to deliver summer schools and discovery days.
- According to PayScale, the average salary for a cell biologist in the UK is £33,320.

PATHWAY FROM SCHOOL TO CELL BIOLOGIST

Pascale recommends taking mathematics, biology, physics and chemistry at school to prepare for a relevant undergraduate degree. Many undergraduate degrees can lead to a career in cell biology – examples include biology, chemistry, medicine, natural sciences and biochemistry.

ELIZABETH GARRETT ANDERSON: HER LEGACY CONTINUES



Elizabeth was born in 1836 at a time when women's rights were largely limited. Despite vigorous opposition from the medical establishment, she passed her medical exams in 1865 and became the first female doctor to qualify. Elizabeth fought tirelessly for women to have high-quality healthcare and the right for women to practise medicine, and, aged 36, she founded the first hospital for women in Britain. After her death in 1917, the hospital was renamed the Elizabeth Garrett Anderson Hospital.

This hospital no longer exists but Elizabeth's legacy continues with the Elizabeth Garrett Anderson Institute for Women's Health at University College London.

<https://www.ucl.ac.uk/womens-health/about-institute/our-history>

PASCALE'S TOP TIPS

- 01 Never stop dreaming and persevering. Your goals are within reach.
- 02 Science is all about failure. Failure will ultimately make you succeed.

HOW DID PASCALE BECOME A CELL BIOLOGIST?

YOU HAVE A BSC IN MATHEMATICS AND PHYSICS AND A PHD IN NEUROSCIENCE. HOW HAVE THESE DIVERSE SUBJECTS AIDED YOUR CAREER?

I feel mathematics and physics are essential in biology as we often make calculations and build models. Cell biology can be approached from many different angles – for instance, neuroscience involves the study of cells of the nervous system. Even though neuroscience involves different types of cells to the ones I work with now, all cell biology is centred on understanding how our organs work at the cellular level.

This understanding can be applied in many different contexts.

WHAT INSPIRED YOU TOWARDS A SCIENTIFIC CAREER?

My inspiration came from very early contact with the scientific community through my parents. I have always thrived on challenges and working on the edge of discovery to pioneer new therapeutics.

WHAT SETBACKS HAVE YOU EXPERIENCED IN YOUR LIFE?

I used to compete in high-level taekwondo competitions. Though I never aimed to

become a professional athlete, I have always believed a connection between body and mind is a great complement to intellectual work. However, taekwondo left me paralysed in one leg, and it took me ten years from the moment I was told I would never walk again to be able to walk without limping and eventually start a new path with yoga.

WHAT ARE YOUR HOPES FOR THE FUTURE?

I hope that we keep on discovering how to live longer lives that are healthier both physically and mentally.



The tissue culture room at the Zayed Centre for Research into Rare Disease in Children, where Pascale's team works. Pascale belongs to the Elizabeth Garrett Anderson Institute but works in the Zayed Centre, which is part of University College London (UCL).



The laboratory where experiments are performed.



The lower floor of the Zayed Centre for Research where scientists at UCL work.

UNDERSTANDING THE MECHANISMS BEHIND LYME DISEASE

DR CATHERINE BRISSETTE, BASED AT THE DEPARTMENT OF BIOMEDICAL SCIENCES AT THE UNIVERSITY OF NORTH DAKOTA IN THE US, IS ENGAGED IN A PROJECT THAT SEEKS TO UNDERSTAND MORE ABOUT LYME DISEASE. THE FINDINGS COULD LEAD TO THE DEVELOPMENT OF NOVEL THERAPIES TO TREAT AND PREVENT INFECTION

TALK LIKE A BIOMEDICAL SCIENTIST

PATHOGEN – any organism that can cause disease

BORRELIA BURGDORFERI – the bacterium pathogen which causes Lyme disease

HOST – the organism in which the pathogen resides, such as deer or humans in the case of Lyme disease

VECTOR – any agent which carries and transmits an infectious pathogen into another living organism, such as a tick in the case of Lyme disease

TROPISM – a biological phenomenon, indicating growth or movement of an organism in response to an environmental stimulus

Lyme disease is a bacterial infection that can affect humans if they are bitten by infected ticks. Symptoms of Lyme disease include a circular red rash, high temperature, headaches, muscle pain and fatigue. The infection is treated with antibiotics and most patients get better relatively quickly, but there are others who experience severe symptoms that can last for months.

There are approximately 500,000 cases of Lyme disease every year in the US and it is also prevalent across Europe and parts of Asia. Scientists are aware of how the disease

is spread and how to treat it – especially when the infection is discovered early. However, there is still much we do not know about the bacterium that causes the disease (known as *Borrelia burgdorferi*), and why some people experience far more serious cases of the disease than others. It is also not known why some patients continue to suffer from long-term symptoms, even after treatment.

To develop understanding in these areas, Dr Catherine Brissette is conducting research that is centred on discovering how the microbes that cause the disease persist and cause long-

term infections. Catherine is a biomedical scientist based within the School of Medicine and Health Sciences at the University of North Dakota in the United States. Some of the questions her team is seeking to answer include why *Borrelia* have a tropism for certain tissues, how *Borrelia* cause disease, and how *Borrelia* survive in the vector and the host.

HOW DOES CATHERINE PERFORM HER RESEARCH ON A DAY-TO-DAY BASIS?

Some of the processes that Catherine and her team are engaged in are laborious – but that is often the case with research! “A typical experiment starts with growing the bacterium, which can take a week! A typical infection experiment starts with an intense day of inoculating mice, followed by waiting,” explains Catherine. “Most of our experimental work, whether it is creating strains of *Borrelia* that lack a particular virulence factor, or an infection experiment to examine how the bacterium colonises the host, or what the host immune response looks like at a particular time point, is a lot of hurry up and wait.” For this reason, the team tends to have several different projects ongoing at any one time, so that they can stagger the work and achieve results.



WHAT HAPPENS IN THE HUMAN BODY WHEN A PERSON IS INFECTED?

Lyme disease is a tick-borne disease caused by tick bites. The tick will bite an animal infected by Lyme disease, such as a deer, and act as a vector through which the infection is transmitted to humans. The bacterium enters a patient through the skin after a bite and the immune response follows the bacterium. *Borrelia* itself does not make toxins, so the severity of the disease is dependent on how an individual's body responds to the infection.

There are a range of different symptoms, many of which are similar to flu. However, it can also cause temporary facial paralysis and even serious heart conditions that can lead to death. *Borrelia* target the skin, joints, heart and nervous systems but nobody is sure why this is – it is thought that certain surface proteins of *Borrelia* interact with certain host proteins which could influence where the bacteria end up in the body.

WHAT METHODS DO CATHERINE AND THE TEAM USE?

Animal models are critical to the research that Catherine is conducting. "We use both mice and ticks, because *Borrelia* is spread by ticks in nature. Using these models, we have shown how certain outer surface proteins in *Borrelia* contribute to the spread of the bacteria to different tissues and organs," says Catherine. "We have also shown that – contrary to what people used to think – mice do get central nervous system involvement after *Borrelia* infection. This is important because, previously, people used monkeys to study the neurological effects of Lyme disease, but mice are better for research: there are many more tools and reagents available to do these studies, the research is cheaper, and does not require special facilities or training."

The studies revolve around three distinct (though related) focus groups: host-pathogen interactions, neuroscience and epigenetics, and the team combine all of them to aid their research. "We look at how *Borrelia* impacts the

host response in the central nervous system, so there are the host-pathogen interactions and neuroscience interaction. Epigenetics (above the DNA) refers to changes in gene expression that are inherited (from cell to cell or even from parent to offspring) but are not due to changes in DNA sequence. So, there is a change in how genes are read," says Catherine. "Epigenetics may play a role in why symptoms can vary so widely between people, or why some people have persistent symptoms. For example, a host immune gene might be 'primed' to overreact to a *Borrelia* infection or might not be turned 'off' when the infection is cleared, because of an epigenetic mark."

WHAT HAS THE TEAM DISCOVERED ABOUT LYME DISEASE SO FAR?

Some of the team's results are focused on how the disease affects the nervous system; they have discovered that *Borrelia* colonise the lining of the brain which results in a particular immune response within the brain itself. What is particularly fascinating about this is that the bacteria are not actually in the brain when this reaction occurs. The key factor in the severity of Lyme disease is how the host responds to the bacterium – which differs from person to person. It is likely that the variance in symptoms depends on several factors, such as genetic differences, environmental factors, what particular variety of *Borrelia* is inside the patient and where the bacterium invades the nervous system.

One of the chief successes that Catherine and the team have had so far is convincing the wider field of biomedical sciences that using mice was a viable model system to study the neurological effects of Lyme disease. Indeed, Catherine considers that achievement to be especially validating for her professionally. It will pave the way for further studies in the area which could well lead to additional developments in our understanding.

HOW CLOSE ARE WE TO THE DEVELOPMENT OF NOVEL THERAPIES



DR CATHERINE BRISETTE

Associate Professor, Department of Biomedical Sciences, School of Medicine and Health Sciences, University of North Dakota, USA

FIELD OF RESEARCH

Biomedical Sciences

RESEARCH PROJECT

Catherine's work is focused on the host-pathogen-vector interface involved in Lyme disease. Ultimately, her laboratory wants to discover how the microbes responsible for the disease persist and cause long-term infections in patients.

FUNDERS

National Institutes of Health, University of North Dakota, US Department of Defense

AGAINST BORRELIA BURGENDORFERI?

Catherine believes we are very close to an effective novel therapy (or combination of therapies) being developed. Of course, treatments already exist for Lyme disease, but they are not effective for all patients. There is a lot of work being done on different antibiotic regimens, treatments that can be administered before an individual is exposed to high-risk populations, and work is afoot to create a Lyme disease vaccine.

The key to the majority of cases is early detection, as treatments are much more effective the earlier they are administered. However, there will always be people who experience more serious reactions, so novel therapies to combat long-term symptoms are the holy grail in this research field. Fortunately, Catherine and her team continue to conduct research which will accelerate understanding and could one day lead to treatments and novel therapies that see adverse reactions to Lyme disease confined to the past.

ABOUT BIOMEDICAL SCIENCES

The biomedical sciences get their name from the fact that proponents of it attempt to explain health in terms of biology. Biomedical scientists often conduct research that is designed to understand more about anatomy and systems, including mechanisms like the heart and brain.

It is difficult to overstate the importance of biomedical science as a distinct field, especially when we consider that it has led to increased knowledge about what causes infectious diseases. We have all seen the impact of COVID-19 and the efforts being made to curb the spread of the virus.

However, it is not just infectious diseases that biomedical scientists are concerned with – Catherine’s research is centred on understanding more about the mechanisms that lie behind Lyme disease. The ultimate hope is that by increasing understanding

about why some patients experience more severe symptoms than others, suitable treatments, cures and preventive measures can be developed. Biomedical science is just as important today as it was 100 years ago, although as understanding and technology develops, so too do the methods and approaches that can be undertaken.

WHAT DOES CATHERINE FIND REWARDING ABOUT BIOMEDICAL SCIENCES?

Catherine has enjoyed solving puzzles since she was a child and her role as a biomedical scientist enables her to pursue this interest on a near-daily basis. Of course, the puzzles she is attempting to solve are more difficult than, say, a 1000-piece jigsaw, but the overall objective (solving a challenge) is similar! Catherine also enjoys learning new things and she tells us that even though she did not want to be a physician, she wanted to

be close to medicine and do work that might benefit patients. Her current work certainly involves that!

WHAT ISSUES WILL FACE THE NEXT GENERATION OF BIOMEDICAL SCIENTISTS?

In many ways, the issues biomedical scientists may face in the future will likely not differ too much from those facing scientists of other fields. “Higher education is changing, and academic jobs may be hard to find. Luckily, what used to be considered ‘alternative fields’ are not alternative anymore, so there are opportunities in science writing, industry, law and advocacy,” explains Catherine. “Diversity and equality issues are still a big problem, but institutions and society seem to be paying more attention, and I am hopeful this next generation will make great strides.”

EXPLORE A CAREER IN BIOMEDICAL SCIENCE

- The Annual Biomedical Research Conference for Minority Students (ABRCMS) is a great conference for students that happens in the US every November. ABRCMS promotes STEM for underrepresented students, but their conferences and resources are available to everyone.
- Catherine recommends reaching out to researchers in the field via email or social media. When at college, look for research opportunities in labs and volunteer if you can. Tell your instructors you are interested in research and they will often help you find a place.
- From working in a lab as a research technician, to a faculty or industry position with a PhD, the salary for a biomedical scientist can vary hugely!

PATHWAY FROM SCHOOL TO BIOMEDICAL SCIENCE

Catherine suggests that students study the basics – biology, chemistry, biochemistry and physics, but also think about what interests you. “So much science is collaborative these days and having a broad base of all the sciences can only be beneficial,” says Catherine. “Save some credits for learning something you enjoy – I took psychology courses and Greek mythology just because they interested me!”

You could do a degree accredited by the Institute of Biomedical Science, or train through the NHS Practitioner Training Programme and complete a degree in healthcare science. Your course will include work placements so you can get industry experience and evidence to complete a training portfolio. You’ll need this to register to work.

<https://nationalcareers.service.gov.uk/job-profiles/biomedical-scientist>



Dawn Cleveland, a graduate student, and Dr Catherine Brissette examine a tube of baby (larval) ticks.

CATHERINE’S TOP TIPS

- 01** Perseverance is the key to success. If you stick at what you are doing (even when it is difficult), you will eventually get the results you want.
- 02** Try and take care of your mental health. The job of a scientist can be stressful, so it is important to find ways of managing your stress from the outset.
- 03** Read broadly! This will help keep your mind alive to possibility and retain curiosity. I believe keeping an open mind is extremely important because you never know what is around the corner – often discoveries will come from unexpected places.



HOW DID CATHERINE BECOME A BIOMEDICAL SCIENTIST?

WHAT WERE YOUR INTERESTS AS A CHILD?

I was interested in many things, including nature, animals, music, art and books.

WHO OR WHAT INSPIRED YOU TO BECOME A SCIENTIST?

My parents! My dad was a research scientist with the US Forest Service and my mom was a medical technologist. From when I was six weeks old until I graduated from high school, one or both of my parents was in school! I also love puzzles and consider my role as a scientist to be all about solving puzzles.

WHAT ATTRIBUTES HAVE MADE YOU SUCCESSFUL AS A SCIENTIST?

Persistence. Then there is reading a lot

and learning about other scientific fields. Sometimes you get great ideas from a talk or presentation that has nothing to do with your own research. Having great mentors is also very important and collaborating with other scientists too.

HOW DO YOU SWITCH OFF FROM YOUR WORK?

I enjoy listening to music and have created a playlist of tunes designed to invigorate me! I also enjoy playing music - I play clarinet in a city band and I am currently learning bass guitar. I also like running and doing physical work outside, such as gardening.

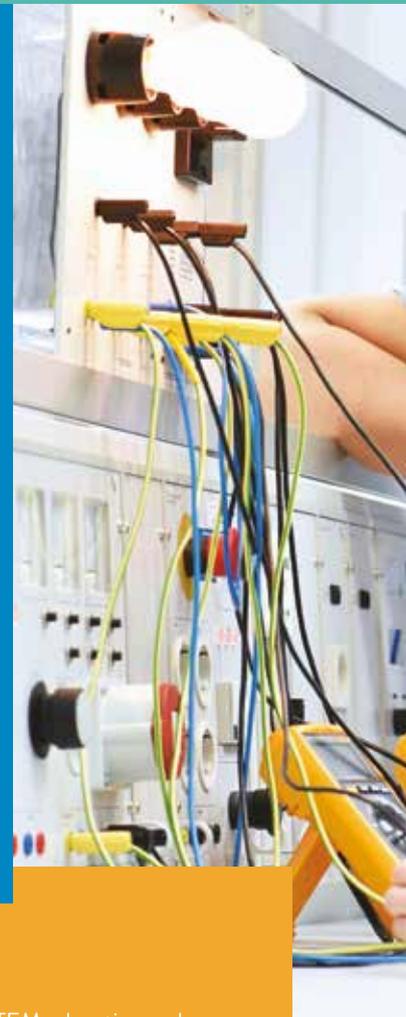
WHAT ARE YOUR PROUDEST CAREER ACHIEVEMENTS AND

AMBITIONS FOR THE FUTURE?

Getting grants and publishing papers always feels good but seeing my students and trainees do well is the best achievement. I would love to see one of my trainees follow in my footsteps and get a tenure track position. For myself I would really like to make full professor!

CAN INDUSTRIES HELP SCHOOLS AND TEACHERS MAKE STEM EDUCATION AND STEM CAREERS MORE ATTRACTIVE TO STUDENTS?

BJÖRN BACHMANN, MANAGER OF THE STEM ALLIANCE AT EUROPEAN SCHOOLNET, EXPLAINS HOW THE STEM ALLIANCE IS BRINGING INDUSTRIES, MINISTRIES OF EDUCATION AND EDUCATION STAKEHOLDERS TOGETHER TO SUPPORT STEM EDUCATION AND ADDRESS FUTURE SKILLS GAPS IN THE EU



ABOUT THE STEM ALLIANCE

The STEM Alliance is a Europe-wide initiative, coordinated by European Schoolnet, that aims to bring together STEM education and STEM careers. It is an ambitious and ongoing collaboration that was created when European Schoolnet's inGenious project came to an end in 2014. It brings together industries, Ministries of Education and other stakeholders to promote STEM education. In real terms, the STEM Alliance is aiming to support teachers with links to industry professionals, who can provide real-world examples of STEM's use and support STEM subjects that are often studied in isolation: www.stemalliance.eu/home



WHAT IS YOUR ROLE IN THE STEM ALLIANCE?

As project manager, I oversee all the different activities, events and projects that we organise within the framework of the STEM Alliance. I also coordinate our stakeholders to come up with concerted actions to address the STEM skills gap. Our stakeholders are the Ministries of Education, industry partners and STEM advocates across Europe.

CAN YOU TELL US A LITTLE ABOUT YOUR BACKGROUND?

My educational background is in political and international studies, but I have always been active in social projects and educational issues. That's why it made sense for me to combine my political and educational interests through a project like the STEM Alliance. I didn't want to be a politician growing up, but I definitely wanted to work in a field that has an impact on society. I think that's where I am now.

WHY ARE YOU PASSIONATE ABOUT STEM EDUCATION?

What comes to mind when many people think about STEM is periodic tables, chemistry, and complicated maths formulas and graphs. It was the same for me at high school. But STEM is so much more than that; it really has an impact on our daily lives. For example, we're chatting over Zoom and your readers will read this article online. Simple, day-to-day activities like these, and technologies like ovens and fridges, all come from science.

It's important that we have at least a basic understanding of STEM, so that we can become analytical, responsible and innovative citizens of the future – and be able to tackle all the challenges we face, such as climate change, mobility, sustainable energy and so forth.

DEMAND FOR STEM PROFESSIONALS IS EXPECTED TO GROW BY 8% BY 2025 AND YET EUROPE IS EXPERIENCING A SHORTAGE IN STEM SKILLED WORKERS. HOW CAN WE SOLVE THIS ISSUE?

It's important is to address this issue in a concerted way. We cannot work in isolation, where each company, each government, each teacher tries to address STEM issues alone. That's why we need platforms like the STEM Alliance to bring initiatives together, share approaches, and exchange good practices with all stakeholders.

Many companies and policymakers are addressing STEM studies and careers at the university level, but we believe that foundations need to be laid at an earlier level – at primary school. We need to support



MORE ABOUT...

EUROPEAN SCHOOLNET

European Schoolnet was founded in 1997 and is a network of 33 European Ministries of Education, based in Brussels.

schools, teachers and students with innovative pedagogies for teaching STEM subjects.

I also think it's important to contextualise STEM education. Currently, STEM education in Europe seems abstract and detached from real life, and I think it would help if students were taught just how important STEM is.

HOW DOES THE STEM ALLIANCE SUPPORT TEACHERS?

We tackle two core phenomena: lack of interest in STEM subjects in schools and lack of interest in STEM jobs. To do this, we have partnered with 16 companies, including Microsoft, LEGO Education, Dell Technologies and Amgen Europe, as well as Ministries of Education across Europe.

Just to be clear, I think teachers are doing an amazing job, but it's important to support them with teaching materials and continuous professional development. As such, we organise conferences, online events and competitions, specifically aimed at teachers. For example, we ran a competition with LEGO Education, which called on teachers to integrate LEGO Education resources into the classroom. We also promote companies' existing STEM initiatives, which contextualise STEM education and encourage collaboration between industries and the education sector.

YOUR INDUSTRY PARTNERS PROVIDE SOME FANTASTIC RESOURCES, WHICH ARE UPLOADED TO THE STEM ALLIANCE'S PRACTICES REPOSITORY. HOW MANY RESOURCES ARE AVAILABLE ON THIS REPOSITORY?

The repository features hundreds of resources, publications and CPD opportunities. Both educators and students can access webinars and talks. For example, Microsoft hosted a webinar on artificial intelligence

earlier in the year, which is available on our site, and there are many more like this.

THE STEM ALLIANCE ALSO PROVIDES RESEARCH-BASED INSIGHT ON VARIOUS STEM EDUCATION AND CAREERS SUBJECTS. WHAT IS THE LATEST INSIGHT?

One report carried out by European Schoolnet and supported by Amgen Europe and the STEM Alliance investigates the attractiveness of STEM subjects. It looks at how to make STEM studies and careers more appealing to youth in Europe.

Another report produced in collaboration with STE(A)M IT found that, in Europe, most STEM subjects are taught in isolation. So, rather than having an overarching STEM class, science is divided into physics, chemistry and biology, and maths and technology classes are taught separately. To get students to see just how important STEM is, and interested in STEM degrees and careers, it's important to teach STEM subjects in an integrated way.

WHAT ADVICE DO YOU HAVE FOR TEACHERS OF STEM SUBJECTS?

I think the advice that I could pass on to teachers is that they're in the driving seat. They can decide where the focus needs to be and think creatively about how to achieve this focus. One example is partnering with local businesses or shops, just as one teacher did when they worked with a local pharmacy to deliver maths classes.

Some teachers may fear that businesses are simply advertising their products, but that's not what the STEM Alliance is about. It's about making STEM subjects more attractive, and supporting innovative practices in STEM teaching, to contextualise STEM education and increase interest in STEM, overall.



DO INDUSTRIES INFLUENCE GOVERNMENT REGULATORY AGENCIES?

HOW MUCH INFLUENCE DO INDUSTRIES HAVE OVER THE REGULATORY AGENCIES RESPONSIBLE FOR POLICING THESE SAME INDUSTRIES? THIS IS WHAT DR EVA HEIMS AT THE UNIVERSITY OF YORK IS HOPING TO DISCOVER, AND IT MAY BE LESS THAN THE MEDIA WOULD HAVE US BELIEVE

TALK LIKE A POLITICAL SCIENTIST

CAPTURE – the idea that an agency that is supposed to act for the good of all society is excessively influenced (captured) by one particular group

INDUSTRY INFLUENCE – when individual companies or industrial sectors (e.g. the energy or finance industries) are able to influence government decisions

POLITICAL SCIENTIST – a researcher who studies an aspect of politics, such as how governments work or how policies are made

POLITICIAN – a person elected (or seeking to be elected) by the public to work in the government

REGULATORY AGENCY – a government institution responsible for monitoring a sector of public life, usually to protect the public from unsafe products and business practices

REVOLVING DOOR – the movement of individuals between industry jobs and related jobs in government

Regulatory agencies are the government institutions responsible for monitoring a wide range of activities in the UK, to ensure that the public is treated safely and fairly.

Your school will be inspected by Ofsted and your exams will be monitored by Ofqual to check that all candidates are fairly assessed. The Civil Aviation Authority ensures that planes are safe to fly, the Food Standards Agency checks that food is safe to eat, Ofgem determines the maximum price that energy companies can charge us for electricity and gas, and the Environment Agency monitors our water quality.

Most of the time, we are unaware of the decisions made by regulatory agencies, despite the fact that they have such an impact on our daily lives. But public awareness has recently increased as a result of the COVID pandemic, when the process of creating vaccines has been at the forefront of the news. Once a laboratory has developed a vaccine, it must be approved by the Medicines and Healthcare products Regulatory Agency (MHRA), which is responsible for ensuring that the vaccine is safe and effective, before it is administered to the public. Different countries have their own regulatory bodies to monitor activities. For example, the Food and Drug Administration (FDA) was responsible

for approving the COVID vaccines in the USA, while the European Medicines Agency (EMA) approved them in the EU.

“These regulatory agencies are in charge of very important issues that affect all of us,” explains Dr Eva Heims of the University of York. “However, unlike politicians in cabinet or parliament, they are not elected by the public, but are recruited on the basis of their professional expertise.”

WHAT IS THE PROBLEM WITH UNELECTED REGULATORY AGENCIES?

Some people worry that the regulatory agencies responsible for monitoring all these aspects of our lives – and more – are being influenced by industries, and that this influence enables industries to benefit in some way to the public’s detriment. This is what political scientists call ‘regulatory capture’. If a government institution has been ‘captured’, then a particular sector of society (usually a private industry) has excessive influence over the regulatory agency, and so is able to control the decisions made. “This means that captured government institutions do not work in the interests of us all, but only for the benefit of a particular group in society, such as a particular company or a whole industrial sector,” explains Eva.

A theoretical example of capture would be a regulatory agency that does not stop the sale of a dangerous product because of industry influence. The company producing the product wants to make more money by continuing to



sell it, and so they use their industry influence over the captured regulatory agency to convince the agency to keep the product on the market, despite its potential harmful effects.

HOW PREVALENT IS REGULATORY CAPTURE?

That is the question that Eva is hoping to answer with her project Capture Revisited. The public often imagine that regulators are excessively influenced by industry due to the 'revolving door' concept. This is when people with expertise in one particular area move between jobs in private industry and government regulatory agencies. For example, someone with experience of banking may work in a finance company and then move to a job in a finance regulatory agency. "This can lead to close relationships between regulators and the industry, which raises concern about industry influence," says Eva.

So, let's consider our banker again. They originally worked for a private company but then moved into a finance regulatory agency. They may use their new position to persuade the regulator to make decisions that benefit their old friends in the finance company. As a result of the banker's influence, the regulator may allow large financial companies to increase their profits while not protecting the public whose money is being used.

Sometimes, regulators make bad decisions. A financial company is able to exploit its customers, or a harmful drug is given to patients. When this happens, the media like to blame industry influence and accuse the regulatory agencies of having been captured. Politicians also like to blame the agencies because it can detract from their own close relationships with private companies. But some of this blame may be unjustified. "This is not to say that industry influence does not exist," says Eva, "but it is very difficult to show with good evidence that

government agencies did certain things because of industry influence and that society has been harmed as a result of this."

WHY SHOULD WE TRUST REGULATORY AGENCIES?

There are several reasons why regulatory bodies are likely to be more trustworthy than the public gives them credit. "People who work in regulators are experts in their field and have usually invested many years in education and professional training to become, for example, a scientist or an economist," says Eva. "This means most of them have strong professional values and believe that decisions should rest on the best available expertise."

A scientist or economist will usually earn a higher salary if they work in private industry rather than in a government regulatory agency. So those who choose to work in regulators usually do so deliberately because they strongly believe in serving the public interest. These factors can provide protection against industry influence.

HOW IS EVA ASSESSING THE SCALE OF INDUSTRY INFLUENCE?

In most studies, if researchers identify a route to industry influence, such as the revolving door, then they simply assume that there is also excessive industry influence, with no consideration of how (or even if) the revolving door is actually leading to industry influence.

Eva is investigating this missing link, to understand exactly how and if industries influence regulators. She is using a technique called comparative process-tracing analysis. "Process-tracing is a research method that requires the researcher to uncover how a cause (such as the revolving door) results in a particular outcome (such as capture)," explains Eva. "Comparing different cases of decision-making of regulators allows me to get a better sense



DR EVA HEIMS

Lecturer
University of York, UK

FIELD OF RESEARCH

Politics, specialising in Comparative
Public Policy

RESEARCH PROJECT

Capture Revisited aims to challenge the notion that industry influence and capture of regulatory agencies is inevitable.

FUNDER

This work is supported by the Economic and Social Research Council under grant number ES/S013253/1

of how common particular routes to industry influence are (or are not)."

SO, DOES INDUSTRY INFLUENCE OCCUR?

Through her research, Eva has discovered that even in cases where regulatory agencies have been publicly accused of having been captured, it is very difficult to find evidence of excessive industry influence. "My research highlights that sometimes regulators take bad decisions not because they have been influenced too much by industry, but because there was limited knowledge on the subject when they had to take decisions," she says. "However, my research also shows that regulators have a certain level of trust in the companies they regulate, and sometimes fail to consider the possibility that some companies can be untrustworthy and can act unethically."

Understanding the factors that may cause regulatory capture is crucial for preventing industry influence. It is equally important for preventing blame being unfairly shifted to regulators. As these regulatory agencies are responsible for decisions that affect so many aspects of our lives, it is essential that we feel we can trust them.

ABOUT POLITICAL SCIENCE

Do you sometimes think about the Prime Minister and what he/she does to serve the public? Do you remember highly charged election campaigns? Or maybe you think about a politician who has been in the news recently. These are all aspects of politics, and are the parts we hear most about in the media. But politics is about so much more than government ministers and elections. Politics covers all aspects of how governments work, from how and why laws are created, to different types of government systems and international relationships between countries. Political scientists are the researchers who study these different aspects of politics.

COMPARATIVE PUBLIC POLICY

Eva is a political scientist specialising in comparative public policy. “Public policies have a huge impact on us all on a daily basis, yet the nitty gritty details of how policies are made are often ignored in public discussion because they are overshadowed by the drama of political elections and big speeches,” she says. “I think

the study of public policy and regulation is incredibly important if we want to understand what effects government has on society, and why.”

The ‘comparative’ aspect is because Eva compares public policies across different systems and institutions to help understand what makes some policies work and others fail. By studying policies used in different countries, governments can learn which methods are most successful, and may adopt policies used elsewhere. “The COVID pandemic is a very good example of this,” says Eva, “because we are seeing many comparisons of policies to curb the spread of the virus across different countries, which can help us to understand what the most effective tools are.”

WHAT ROLE DO POLITICAL SCIENTISTS PLAY?

The research conducted by political scientists often influences policies as the results from their work may be used by politicians, civil

servants and industries. This is important because academic research is needed to provide the evidence on which good public policies are based.

“The fantastic thing about an academic career in politics is that you can truly follow your passion and study what interests you,” says Eva, “be it why governments are so ineffective at tackling climate change, the role of protest movements such as Black Lives Matter in politics, or something else altogether.” But political scientists do not just work as academics within universities. There is also a need for political scientists in civil service roles, as researchers for think tanks and for positions in local government.

Is there a policy that you disagree with? Do you think that an area of the government could be improved? If so, perhaps a career in political science will enable you to bring about a positive change for the country.

EXPLORE A CAREER IN POLITICAL SCIENCE

YouthPolitics UK (www.youthpolitics.org.uk) is a non-profit organisation that aims to give the young a voice, and the Political Studies Association (www.psa.ac.uk) brings together all political scientists in the UK and provides resources for anyone interested in politics.

If you pursue an academic career in politics, your average salary will be around £41,000.

If you are interested in becoming politically active, you can join your local branch of a political party.

PATHWAY FROM SCHOOL TO POLITICAL SCIENCE

At school, taking politics, history, economics or sociology classes will be good preparation for a career in politics or political science, though as Eva says, “most subjects have relevance for politics.”

Most universities offer degrees in politics, political science or international relations.



Students at the University of York Library. Credit: University of York, John Houlihan

EVA'S TOP TIPS

- 01** Follow your passion.
- 02** Read and write about your interests as much as possible.
- 03** Don't be afraid to engage your teachers in conversations about the ideas that fascinate you.



● HOW DID EVA BECOME A POLITICAL SCIENTIST?

HAVE YOU ALWAYS BEEN POLITICALLY MINDED?

I think so. As long as I can remember, I've always been interested in what is happening in our societies and why. I think that interest was first sparked by concerns about animal welfare when I was a child and what was being done about it, and it developed from there.

YOU HAVE A BA, MSC AND PHD IN POLITICS. WHO OR WHAT INSPIRED YOU TO FOLLOW A CAREER IN THIS FIELD?

I would like to be able to say that one person or event inspired me, and that I always knew that I would follow this path, but that would not be true at all! I think at every step of the way, I met new friends and teachers who inspired me to take the next step. Without the encouragement and support of my teachers and professors along the way, I would not have managed to continue on this path.

WERE YOU INVOLVED IN POLITICAL ACTIVITIES WHEN YOU WERE YOUNGER?

As a child, I was very concerned about the environment and endangered species (especially whales) and I founded a local youth group under the wings of Greenpeace. I think that was my earliest experience of being politically and societally engaged.

AS A 'COMPARATIVE' POLITICAL SCIENTIST, DO YOU FIND YOURSELF COMPARING SERVICES OR PRODUCTS IN OTHER AREAS OF YOUR LIFE?

Yes, for better or worse, it seems to be an occupational hazard! If I'm honest, I probably do this in all areas of my life, but sometimes it would be better not to spend so much time comparing restaurants before you choose which one to go to!

DO YOU THINK THE GENERAL PUBLIC IS BECOMING MORE OR LESS ENGAGED IN POLITICS?

We went through a long period of people becoming politically disengaged from the 1990s onwards. But over the past five to ten years, many people have become engaged in politics. While it is good that people take more of an interest in politics now, the situation we now face is still very problematic because opinions are so polarised (think of Brexit in the UK or 'Trumpism' in the US). People on every 'side' are just talking to themselves and are completely dismissing the viewpoints of their 'opponents'. For democratic politics to stay healthy, we need more genuine debate between different viewpoints and a willingness to engage with each other.

HOW ONE MASSIVE STUDY IS UNCOVERING THE SECRETS OF UK SOCIETY

THE UNDERSTANDING SOCIETY PROJECT, RUN BY THE UNIVERSITY OF ESSEX IN THE UK, IS A GIGANTIC LONG-TERM STUDY THAT INTERVIEWS HOUSEHOLDS YEARLY TO EXPLORE A HUGE ARRAY OF LIFE EXPERIENCES. DR ALITA NANDI AND NICOLE D. JAMES BOTH WORK ON THE PROJECT, ENSURING THE SUBSTANTIAL QUANTITIES OF DATA COLLECTED CAN BE USED BY RESEARCHERS TO SHED LIGHT ON SOCIETAL TRENDS WITHIN THE UK

TALK LIKE A QUANTITATIVE SOCIAL SCIENTIST

CAUSALITY – when one variable has an effect on another

CORRELATION – when two variables appear to be connected but may be affected by another variable, rather than being linked

LONGITUDINAL STUDY – a study involving several observations of the same subjects over a period of time, sometimes many years

QUALITATIVE DATA – non-numerical data that describes qualities or characteristics

QUANTITATIVE DATA – numerical data that can be statistically processed

*What do you do for a living?
Did you go to university?
Do you exercise regularly?
Did you get bullied at school?
Are you happy?*

These are some of the questions that the Understanding Society project asks of its participants every year. The project was set

up by the Economic and Social Research Council in 2009 to regularly interview the members of 40,000 UK households from many different walks of life. By tracking how the members of these households change over time, researchers get a window into how lives change, and for what reasons. This is helping them track societal trends, and what they mean for well-being, equality and many other factors. Dr Alita Nandi and Nicole D. James work at the Institute for Social and Economic Research (ISER) at the University of Essex, in the UK, which is leading the project, to help ensure the data collected is used as effectively as possible.

“We interview the same set of people every year, so that we get a clear picture of their lives and how they are changing,” says Alita. “Researchers can use this information for all kinds of purposes – to see the similarities and differences in people’s lives, and whether these are controlled by people’s own actions and beliefs or rather by wider society. These answers can be used by voluntary organisations, activists, and policy makers to help them lobby for and implement policies for positive change.”

For instance, there is interest in the link between social media used by young people and levels of happiness. “Does increased use of social media make young people unhappy or do young people who are unhappy due

to other issues – such as bullying – choose to spend more time connecting with like-minded people on social media?” says Alita. “It’s important to understand which is true, as it impacts how policies try to deal with the issue.” The Understanding Society project can help since it collects data every year – so, for instance, if researchers analysing the data find that individuals report being bullied before they report increased social media use, the second hypothesis is better supported.

DR ALITA NANDI

Dr Alita Nandi leads the Outreach team for Understanding Society. “Our team helps researchers understand how to use the data collected, through our user support forum and helpdesk, training workshops and online guidance,” she says. Setting up the questionnaire took some careful thought, especially due to its large size and duration. “We consulted with researchers, policy makers, voluntary organisations and the general public to find out what questions they wanted us to ask,” says Alita. “Then, we consulted survey methodologists, who have expertise in how to design questions that are clear and easily understood.” The questionnaires are also tailored so that respondents are only asked relevant questions – so unemployed people will not be asked about their salary, for instance.



Once the data is collected, it is anonymised and handed over to the data team. “The data team formats the data so that they can be used by researchers for analysis,” says Alita. This analysis can lend important insights into how global events, like COVID-19, affect society. “We asked participants to complete short monthly questionnaires about their lives during the coronavirus pandemic,” says Alita. “Responses from November 2020 indicated that people from ethnic minority backgrounds would be less willing to take a vaccine if offered. This was presented to the government, who then launched a campaign encouraging uptake of the vaccine by ethnic minorities.”

INCENTIVE FOR CHANGE

This real-world impact helps motivate Alita. “Findings from my research have been presented to government departments, parliamentary select committees, and voluntary organisations,” she says. “While conclusions may sometimes seem obvious, having the data to back it up means that it is more likely to translate into action.” One project Alita works on involves examining ethnic minorities’ experiences with racism. “We found that around one in ten people from ethnic minorities in England have experienced a racially-motivated physical or verbal attack in the last year,” she says. “We also found these experiences negatively affect mental health.” Now that these statistics exist, there is added incentive for policy makers to do something about it.

NICOLE D. JAMES

Nicole got involved in the Understanding Society project when she joined as a Survey Data Officer in 2017, towards the end of her master’s degree. She now also uses the project’s data for her PhD research. “I work

on data receipt and release, which involves various forms of data processing, quality checking and programming,” she says. “One of my main roles involves checking the data are consistent and ensuring any errors are investigated. I have automated parts of these processes, making it far more efficient, allowing us to increase the amount of checks we can do in an often short time period and focus on developing other parts of the survey process.”

FAMILY VALUES

Nicole also works on specific projects within Understanding Society, such as the family matrix project. “We collect relationship data from households, but households change over time so it can be difficult to track how these relationships evolve, especially when people move in and out of the household,” she says. “The family matrix project involves creating another dataset to pinpoint these relationships over time.” This will be very useful for researchers, such as those studying separated families and same-sex families.

“It’s important to undertake methodological survey research to see how we can improve the survey process and produce higher quality data,” says Nicole. “My PhD research focuses on nonresponse and panel attrition – the process where respondents drop out of the survey (temporarily or permanently). Surveys such as Understanding Society aim to represent the UK population, so as fewer people participate, the survey can become less representative and the findings from the data, less accurate. Attrition is an inevitable part of the survey process, so we want to understand when, how and why this happens to reduce it or account for it our analyses.”



DR ALITA NANDI

Senior Research Fellow & Associate Director for Understanding Society
University of Essex, UK



RESEARCH INTERESTS

Ethnic & gender differences in economic and subjective wellbeing, including mental health; causes and consequences of discrimination and harassment



NICOLE D. JAMES

PhD Student & Survey Data Officer for Understanding Society, Institute for Social and Economic Research
University of Essex, UK



FIELD OF RESEARCH

Survey Methodology



RESEARCH INTERESTS

Nonresponse and panel attrition, data management and processing



PhD FUNDER

University of Essex



Understanding Society is an initiative funded by the Economic and Social Research Council and various Government Departments, with scientific leadership by the Institute for Social and Economic Research, University of Essex, and survey delivery by NatCen Social Research, Kantar and Ipsos MORI. The research data are distributed by the UK Data Service

ABOUT QUANTITATIVE SOCIAL SCIENCE

Quantitative social science is a field that uses statistics to uncover trends in society. This involves careful thinking about how fairly abstract terms – quality of life, beliefs and values, for instance – can be quantified into datasets. This is opposed to qualitative social science, which works with non-numerical data. Quantitative social science is more suited to dealing with large sample sizes and finding out trends in whole populations. “My work is very varied, which means I’m constantly learning,” says Nicole. “It was a steep learning curve when I first joined, but with time and the support of my colleagues, I now feel a lot more comfortable handling large amounts of data.”

Uncovering the root causes of patterns in society is a key focus for quantitative social science. “I enjoy finding out the causal link between events and behaviours,” says Alita. “For instance, why do some people get paid more than others – due to the value of their skills, or due to discrimination? Finding a causal link is the most difficult part of research but also the most rewarding.” Having hard data behind these causal links can spur positive action. “Though it’s a cliché, I enjoy knowing I’m contributing to something that will ultimately help improve society,” says Nicole.

As society changes, so too will social science.

“Environmental concerns, in particular how to encourage positive behaviour at individual and institutional levels, are becoming increasingly relevant to us,” says Alita. “The nature of jobs and careers is rapidly changing too, which will open up new areas of research. For instance, does the gig economy offer more flexibility, or more job insecurity and poorer mental health? How does it impact decisions around family and housing? Societies are also becoming more multi-cultural and moving away from a binary gender heteronormative viewpoint. Institutions need to adapt to these changes, and social scientists can help make this happen.”

EXPLORE A CAREER IN QUANTITATIVE SOCIAL SCIENCE

- Many institutions offer outreach services for schools and students, to help them learn more about possible career paths in STEM. The University of Essex’s dedicated outreach team can be found here:

www.essex.ac.uk/information/professional-services/outreach

- Careers in quantitative social science vary widely. According to PayScale, UK graduates with a BSc in Sociology have an average salary of £30,600.

PATHWAY FROM SCHOOL TO QUANTITATIVE SOCIAL SCIENTIST

Alita and Nicole recommend statistics as a useful grounding, as well as sociology, economics and psychology, which all approach human behaviour from a different perspective. At university, many academic pathways can lead to a career in quantitative social science, including sociology, economics, psychology, computer science and data science.

ALITA’S TOP TIPS

- 01** Quantitative social scientists may follow very different career paths, but share a curiosity about human behaviour, a logical approach to solving problems and, often, a strong desire to make the world a more equitable place. If these drivers resonate with you, this could be the field for you.
- 02** It is not easy to know what career is best for you, especially when starting out. It is best to keep an open mind, gather as much information as possible about different careers and your own strengths and interests, and be flexible to changing paths.

NICOLE’S TOP TIPS

- 01** Don’t worry if you’re not sure what career to pursue. Speak to your teachers, who may suggest a career that you never knew existed.
- 02** Coding is an increasingly desirable skill. R and Python have a wide range of applications and are both worthwhile programming languages to begin learning before university.



Nicole at her MSc Survey Methods for Social Research graduation at the University of Essex.

HOW DID ALITA BECOME A QUANTITATIVE SOCIAL SCIENTIST?

WHAT WERE YOUR INTERESTS WHEN YOU WERE YOUNGER?

I grew up in India in a pre-internet world, so my connection to the rest of the world came through books and movies. I loved history, geography and mathematics, which gave me an insight into differences in society.

WHAT INSPIRED YOU TO BECOME A SCIENTIST?

At school, I took economics and, later, psychology, both of which dealt with human behaviour and how we make decisions. I remember learning about the difference between correlation and causality – how it

was thought that coffee intake led to heart attacks, but, actually, coffee consumption and prevalence of heart attacks were both linked to high-stress jobs. I only decided on a career in research during my master's.

WHAT ATTRIBUTES HAVE MADE YOU SUCCESSFUL AS A SCIENTIST?

My aptitude for mathematics, logical thinking and attention to detail have definitely helped – but, most of all, my curiosity about human behaviour.

WHAT HAVE BEEN THE EUREKA MOMENTS IN YOUR CAREER?

Through our research and analysis, we found that the cost to mental health of racial harassment was higher than the mental health cost of being unemployed. This helped to substantiate experiences I had gone through in my own personal life.

WHAT ARE YOUR PROUDEST CAREER ACHIEVEMENTS?

I come from a non-academic family and my relatives have all been very proud and supportive throughout my career. Every milestone, such as receiving my PhD, has been a wonderful moment to cherish with them.

HOW DID NICOLE BECOME A QUANTITATIVE SOCIAL SCIENTIST?

WHAT WERE YOUR INTERESTS WHEN YOU WERE YOUNGER?

I enjoyed cooking, reading, and watching TV shows and movies. In school, I loved maths and psychology, so it makes sense that I'm now involved in quantitative social science.

WHAT INSPIRED YOU TO BECOME A SCIENTIST?

I studied criminology initially, and in my final year found I enjoyed the quantitative side of sociology. Following advice from a lecturer, I then went on to study a Master's in Survey Methods for Social Research, which focused

on quantitative research in large-scale surveys like Understanding Society. After the first term, I realised that this was the field I wanted to be in.

WHAT ATTRIBUTES HAVE MADE YOU SUCCESSFUL AS A SCIENTIST?

Similar to Alita, logical thinking and attention to detail are key. It also helps to have good organisation and time management skills, especially when working on various parts of the survey process at once. Creative thinking and flexibility are very useful for writing code to manipulate the data and adapting

to new software and processes as the survey advances.

WHAT ARE YOUR PROUDEST CAREER ACHIEVEMENTS?

I also come from a non-academic family, so completing my undergraduate degree and master's degree were both great moments. Another achievement was becoming a Survey Data Officer at ISER, especially because it was my first 'real' job. More recently, securing a scholarship to fund my PhD has been a highlight. I am still very early in my career, so I'm looking forward to what comes next!



DID YOU THIS READ RIGHT?

READING IS PERHAPS THE MOST COMPLEX SKILL WE LEARN; IT INVOLVES TURNING INTRICATE SEQUENCES OF SYMBOLS INTO SOMETHING COHERENT INSIDE OUR HEAD. DR JONATHAN GRAINGER OF THE **COGNITIVE PSYCHOLOGY LAB**, FRENCH NATIONAL CENTRE FOR SCIENTIFIC RESEARCH (CNRS) AND AIX-MARSEILLE UNIVERSITY, FRANCE, IS INTENT ON UNCOVERING EXACTLY HOW THIS PROCESS WORKS, THROUGH CLEVER PSYCHOLOGICAL EXPERIMENTATION

TALK LIKE A COGNITIVE PSYCHOLOGIST

COGNITIVE PSYCHOLOGY – the science of how the mind works, covering mental processes such as memory, language and reasoning

COGNITIVE NEUROSCIENCE – the science of understanding the neural basis of mental processes

COMPREHENSION – being able to understand and interpret something

COMPUTATIONAL MODEL – a model that can be implemented on a computer with an aim to simulate a real-world system

DECODING – in the psychological sense used in reading research, the ability to look at written symbols (e.g. letters and words) and translate them into sounds and meanings

LEXICAL – relating to the words of a language

ORTHOGRAPHY – representing spoken language through a set of written symbols

SYNTAX – the way that phrases or sentences are formed by assembling words and other linguistic elements

language comprehension – understanding the underlying language in the first place, which we pick up as infants when we learn to listen and speak. There is then the added element of decoding – taking the symbols we see and translating them into the language we learned to speak. Not everyone is able to do this effectively; people with dyslexia can be competent at spoken language comprehension and highly effective communicators but run into difficulties when trying to decode the words and sentences they see before them.

Reading silently adds another level of complexity, because we are understanding words and sentences without hearing them at all. In fact, silent reading is a relatively new phenomenon and only started to be practised by scholars around the 10th century, whereas written communication dates to about 3500 BC. Jonathan explains, “It is thought to be the transition to silent reading that led to the introduction of spaces between words.” Indeed, it is silent reading that Jonathan’s research currently focuses on.

The human brain is the most complex object in the known universe, and reading is among the most complex tasks it can do. Although most animals, including ourselves, can instinctively communicate with others of their species, we are the only ones that have learnt to do this through writing. “Unlike spoken language skills, learning to read typically requires years of tuition and practice,” says Dr Jonathan

Grainger. He works at the French National Centre for Scientific Research (CNRS) and Aix-Marseille University, as a Research Scientist in the Cognitive Psychology Lab, and has made some fascinating insights into how we read.

COMPREHENDING AND DECODING
Though some of us find it easier than others, reading is no simple task. Firstly, it involves

TRICKY TO TEST
Psychology has an added challenge compared to most sciences – its subject matter, the mind,



is abstract and virtually impossible to observe directly. For instance, how can we tell exactly what is going on in someone’s mind when they are reading silently? Psychological researchers have to get creative with their experimental techniques to answer questions like this.

“To study silent reading, we typically use quite simple laboratory tasks,” says Jonathan. “We may ask people to classify letter strings as real words or not (a lexical decision task) or ask them to classify word sequences as grammatically correct or not (a grammatical decision task).” By recording the accuracy of these decisions, and how long it takes participants to make them, Jonathan can infer the cognitive processes going on behind the scenes.

Other research groups use other methods, such as recording the movements of participants’ eyes as they silently read and using the recorded patterns to infer the underlying cognitive processes. While it may feel like your eyes are travelling smoothly along a line of text, in fact they are jumping from one point of focus to another about four times every second. By analysing how eye movements change when presented with nonsense sentences, for instance, researchers can get insights into how the brain is processing the information they see on the page. Jonathan has worked with other researchers to bring together these two methods through building computational models of reading, developing a unified framework for understanding reading behaviour.

YOUNG READERS

Some of Jonathan’s work involves studying the reading processes of young children. “Many children learn to read when they start

primary school, and evidence suggests the most progress is made during their first year of school,” says Jonathan. Although becoming a skilled reader takes many years, analysing children’s reading patterns at this formative age can help uncover the processes that allow us to learn and to identify words and their meanings when we are reading.

Along with other findings, these studies are advancing scientific understanding. “At the basic level, we find a lot of overlap in the mechanisms underlying processing of letters and words,” says Jonathan. “However, when we look at how people process words compared to processing sentences, we find major differences.” Sentence comprehension relies on syntax – the order of words within a sentence – and processing this is a complex task.

DISCOVERIES

A key way to understanding how reading works is to assess how competent people are at noticing, or overcoming, mistakes. “The transposed-letter effect refers to the relative ease with which we can read ‘txet wtlh jublmed letetrs lkie this’,” says Jonathan. “The transposed-word effect refers to the difficulty we have in detecting the error in sentences like ‘you that read wrong again’.” These findings suggest that we do not process words letter-by-letter, or sentences word-by-word; rather, we process multiple letters or words at the same time, to increase reading efficiency.

People are also better at picking out certain elements in text that makes sense. “The word-superiority effect refers to people finding it easier to identify a single letter when it’s within a real word – such as the B in TABLE versus the B in TOBRE,” says Jonathan. “The



DR JONATHAN GRAINGER

Research Scientist, Cognitive Psychology Lab, French National Centre for Scientific Research (CNRS) and Aix-Marseille University, France

FIELD OF RESEARCH

Cognitive Psychology

RESEARCH PROJECT

Using experimental techniques to determine how skilled readers process words and sentences

FUNDER

European Research Council

sentence-superiority effect refers to the same effect for identifying words in sentences – such as the word ‘car’ in ‘this big car is nice’ versus ‘nice this car big is’.”

PROCESSING POWER

The human brain processes information like a very complex computer. “The ultimate aim of my research is to describe the information processing performed by the brains of skilled readers like a computer program,” says Jonathan. “I aim to uncover the mechanisms by which we can rapidly and efficiently extract meaning from extremely complex sequences of visual patterns.”

Ultimately, research like this has significant real-world applications. For instance, it may help inform efforts to aid people who have dyslexia, helping them to find cognitive approaches to improve their decoding skills. It may also help inform education syllabuses, particularly for young children, and especially for those struggling to learn to read through conventional methods. It may even help people trying to learn a second language, especially if it is a language that relies on completely different comprehension and decoding techniques to their native tongue. The possibilities are endless.

ABOUT COGNITIVE PSYCHOLOGY

WHAT IS COGNITIVE PSYCHOLOGY?

Cognitive psychology provides a blueprint of the laws that govern how the mind works – much like how physics establishes the laws of matter. Its foundations lie in analysing behaviour, through methods developed by experimental psychologists. These days, cognitive neuroscience – which uses brain imaging techniques – provides a valuable extension, but behavioural studies remain extremely important.

HAVE THERE BEEN ANY RECENT BREAKTHROUGHS?

Psychological science is a relatively young science and its recent major breakthroughs

have mainly been in developing methods to investigate the human mind. The next major breakthrough will likely involve bridging the gap between cognitive theories and neural processing – so rather than just inferring how the mind works from behaviour, actually seeing it through the activity of neurons. This is not to say neural theories will replace cognitive theories but connecting the two will allow major leaps in understanding to take place.

IS FRANCE A GOOD PLACE TO STUDY COGNITIVE PSYCHOLOGY?

France has a strong tradition in experimental psychology and this continues to this day. Jonathan explains, “We have strong academic

departments, which also cater to incoming generations. Both the CNRS and Aix-Marseille University offer school visits to laboratories and departments, and both are highly active in communicating their research findings to the public.”

WHY WOULD WE RECOMMEND A CAREER IN COGNITIVE PSYCHOLOGY?

Cognitive psychology is at the forefront of learning about how we perceive, understand and interact with our environment. It is a fascinating field!

HOW TO BECOME A COGNITIVE PSYCHOLOGIST

- An undergraduate degree in psychology provides the most straightforward pathway to a career in cognitive psychology, although other subjects such as natural sciences or biology could also lead in the same direction.
- A number of institutions, such as the NHS in the UK, offer apprenticeships in psychology. These tend to focus on clinical psychology more than cognitive psychology but, as an alternative, some universities offer ‘degree apprenticeships’ that combine part-time studying with employment.
- According to QS World University Rankings, the best universities for psychology are Harvard, Stanford, Cambridge, Oxford and California Berkeley.
- According to Payscale, the average salary for a psychologist in the UK is around £35k. Jonathan points out that salaries in this field can vary widely, however.

PATHWAY FROM SCHOOL TO COGNITIVE PSYCHOLOGIST

Jonathan says that taking maths is an essential at school. Biology, chemistry and physics are also useful for a scientific grounding. Some schools also offer psychology as a subject in itself. Some universities also suggest mixing sciences and humanities for a well-rounded foundation – this could include taking subjects such as English and history.



A volunteer participating in Jonathan's very first combination of EEG (electroencephalography) recordings (the electrodes placed on the red and yellow cap record the brain's electrical activity) and eye-tracking while reading sentences.



● HOW DID JONATHAN BECOME A COGNITIVE PSYCHOLOGIST?

WHAT INSPIRED YOU TO STUDY PSYCHOLOGY?

When I was young, I aspired to become a philosopher. However, when I was in school, I was taught by a maths teacher who helped me excel in the subject and also suggested to me that psychology might offer an interesting compromise between philosophy and maths.

HOW HAS YOUR KNOWLEDGE OF LANGUAGES INFLUENCED YOUR

RESEARCH DECISIONS?

I am English-French bilingual. After studying psychology at the University of Manchester, I moved to France and my French language skills became more proficient. This was the motivation for me to initially focus on bilingualism and second-language learning within my research.

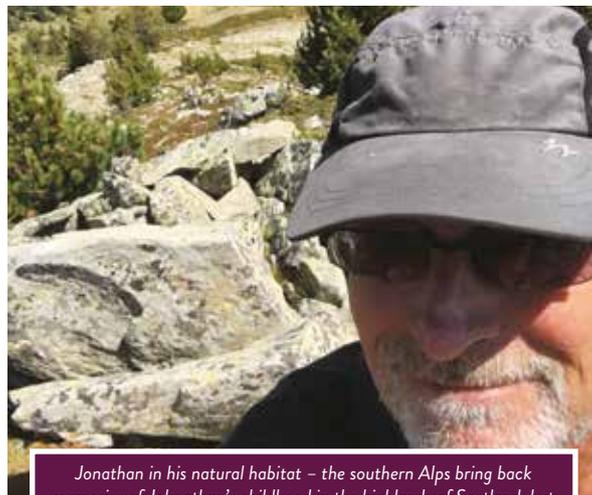
WHAT DO YOU LIKE TO READ?

As a teenager, I read books that covered

philosophical thought and psychological issues. This included novels such as *The Glass Bead Game* by Herman Hesse, *Zen and the Art of Motorcycle Maintenance* by Robert Pirsig, and *The Catcher in the Rye* by J. D. Salinger. I now read more down-to-earth novels, and I am currently enjoying Peter May's Lewis trilogy, which paints a brilliant picture of the Outer Hebrides, not so far from where I grew up.

JONATHAN'S TOP TIPS

- 01** The greatest quality for a scientist is simple curiosity. This is followed by a good dose of creativity, to go beyond what has already been done.
- 02** You will need to find a balance between creativity and perseverance. You can't go wildly chasing after everything that catches your interest, but bearing with one particular question can lead you to a satisfying answer.
- 03** Of course, to be able to answer the questions you raise, you need to be capable of mastering the techniques that will help you provide these answers. This implies not just technical skills, but mostly logical skills.



Jonathan in his natural habitat – the southern Alps bring back memories of Johnathan's childhood in the highlands of Scotland, but with much sunnier weather!

SOLVING THE TOWER OF HANOI

THE TOWER OF HANOI IS A BEGUILING PUZZLE THAT HAS ENTRANCED MATHEMATICIANS FOR ALMOST 140 YEARS. DESPITE ITS APPARENT SIMPLICITY, IT CONTINUES TO YIELD NEW SURPRISES – AS MATHEMATICS PROFESSOR DAN ROMIK CAN TESTIFY. HIS WORK HAS REVEALED NEW SECRETS ABOUT THE PUZZLE, AND THROUGH IT, IMPORTANT LESSONS FOR THE WIDER WORLD OF MATHEMATICS

TALK LIKE A MATHEMATICIAN

DISCRETE MATHEMATICS – the study of mathematical structures that are countable and separable, rather than continuous

EXPONENTIAL – IN MATHEMATICS, CONTAINING AN EXPONENT – a number that shows how many times another number is to be multiplied by itself

FRACTAL – a shape for which any part is a larger or smaller version of another part. Watch this BBC Ideas video on YouTube for a detailed explanation: https://www.youtube.com/watch?v=w_MNQBWQ5DI

RECURSION – the repeated application of a procedure that involves breaking down the procedure into smaller, similar parts

TOWER OF HANOI – a mathematical puzzle involving moving a tower of discs from one pole to another, while obeying certain rules

In 1883, a French mathematician named Édouard Lucas came up with an intriguing scenario. There are three poles in a row, the one on the left containing a series of discs of decreasing size, with the other two, empty. The aim is to move the tower, one disc at a time, over to the right-hand pole. However, the catch is, a larger disc can never sit on top of a smaller disc. This puzzle quickly reached fame as the brainteaser now known as the Tower of Hanoi.

Despite it seeming initially perplexing, in truth the Tower of Hanoi is a problem that even amateur puzzlers can solve with a bit of lateral thinking. However, underlying the puzzle are some key mathematical ideas – even if we might not appreciate them when solving it. Professor Dan Romik, of the University of California, Davis, has investigated the Tower of Hanoi and, despite the puzzle's apparent simplicity, has shown that it continues to yield new surprises.

RECURSION

“Recursion is the extremely useful idea of solving a large problem by reducing it to smaller instances of the same problem,” says Dan. For instance, imagine you have eighty

coins and a set of balance scales. All the coins weigh the same, apart from one that weighs slightly less. To find this lighter coin, one solution would be to weigh and compare two coins at a time to see if there is any difference in weight – but this method would take ages. A faster way would be to divide the pile into two piles of forty and weigh these two piles against one another. You can select the lighter pile and discard the other forty coins all at once. You then repeat this process, dividing the pile into two twenties, two tens, and so on, until you narrow it down to the one coin.

The Tower of Hanoi can be solved using recursion too, which helps mathematicians find the way to solve the puzzle in the fewest number of steps possible. Ultimately, it involves constructing and reconstructing progressively larger ‘towers’, until the bottom disc can be moved to the third pole and the rest of the tower constructed upon it, as the text box explains in mathematical terms (See ‘Solving the Tower of Hanoi through recursion’ on the third page). The more discs that the puzzle contains, the more steps it will take – rising exponentially, in fact. This can be written in algebraic form:



$$S = 2^N - 1$$

In this formula, S is the number of steps, and N is the number of discs. So, if the tower had five discs, the formula would be $2^5 - 1$, which is 31. Therefore, solving the puzzle would take a minimum of 31 steps. If it had four discs, it would require only 15 steps – and for three discs, only 7.

Interestingly, this formula can lead us back to the Tower of Hanoi's supposed mythological roots. The legend goes that young priests of a Hindu temple were tasked with moving discs of pure gold according to the rules of the puzzle – except that their Tower contained not 5 but 64 discs, and it was said that when they completed the task, the world would end. Using the formula above, we can deem that this is highly unlikely, given it would take them many billions of years to complete! Since this legend was invented by Lucas as a marketing ploy, it is hardly surprising that the underlying mathematics do not allow this apocalyptic prophecy to be put to the test.

GRAPHICAL REPRESENTATION

To visualise not only how many steps are needed, but exactly which steps too, the Tower of Hanoi configuration can be represented on a diagram that mathematicians call a graph. Graphs uncover aspects of a particular scenario that might have otherwise gone unseen, in particular by connecting them to other scenarios that may be better understood.

“Many problems in discrete mathematics can be translated onto a graph, such as scenarios that involve flipping a switch or making a move in chess,” says Dan. “Once you have represented the problem this way, you can spot connections to other problems you already know about.”

This mode of thinking originated when mathematician Leonhard Euler was tasked with the ‘Seven Bridges of Königsberg’ challenge in 1736. Königsberg was a Prussian city bisected by a river that contained two large islands. The four areas between the islands and the two sides of the city were connected by seven bridges. Euler’s challenge was to find a route through the city that involved crossing all seven of the city’s bridges exactly once. He realised that the simplest way to approach the problem was to represent it as a graph, where lines (the bridges) connected four points (the banks and islands) in a way representative of the city’s actual layout. Once he had done this, he was able to easily demonstrate that the challenge was impossible. See the image on the right.

“The idea of representing collections of objects as graphs was a revolutionary one at the time it was invented, and remains incredibly useful,” says Dan. A similar simplification process can take place for the Tower of Hanoi. Any possible layout of the discs can be represented using a sequence of numbers. For instance, a Tower with three discs can be represented with a



DAN ROMIK

Professor, Department of Mathematics
University of California, Davis, USA

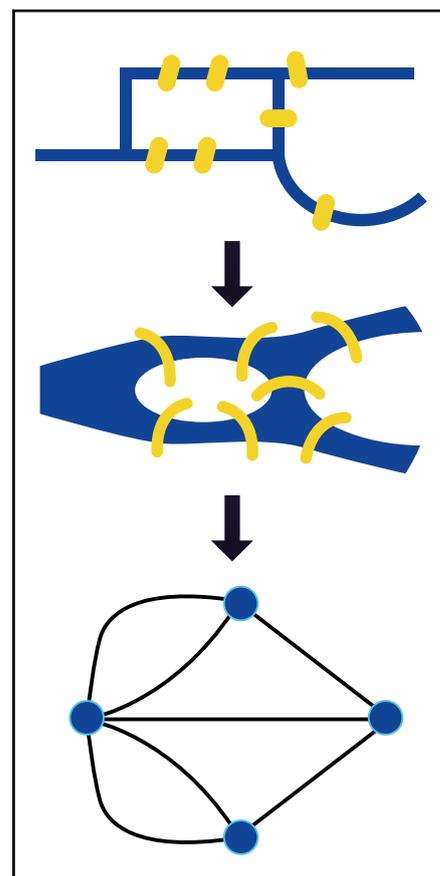


AREAS OF INTEREST

Combinatorics, Probability, Number Theory

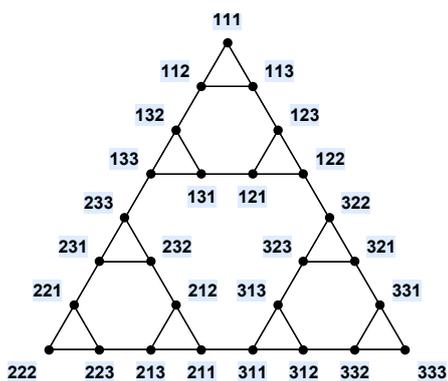


Königsberg was a Prussian city bisected by a river that contained two large islands.

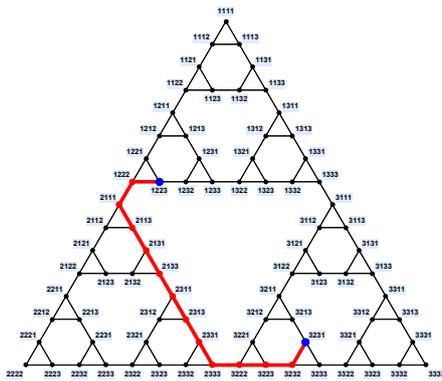


sequence of three numbers, going from the largest to smallest disc. The pole each disc is upon is represented by the value: pole 1, 2 or 3. For instance, the sequence '113' means that the smallest disc is on the third pole and the two larger discs are on the first pole.

These sequences can be used to map out any possible steps from any position – for instance, from '111' you can go to '112' or '113'. These then branch out into other possibilities. It turns out that when all these possibilities are laid out, they can be represented in a very satisfying format – see the image below. As well as being visually pleasing, this also makes it very easy to find the simplest way to complete the puzzle – by finding the shortest route from '111' to



'333'. In fact, this logic can be applied to see how to get from one particular configuration to any other.



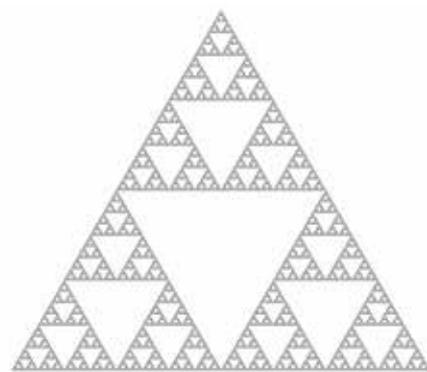
And there is more – because of the Tower's underlying recursive structure, its associated graph is not just any simple graph, but is also a fractal. "The puzzle has turned out to be much more interesting than its inventor probably suspected," says Dan.

FRACTALS

A fractal is a geometric shape that, loosely speaking, contains patterns that repeat themselves at many different scales. Fractals

are often very appealing to the human eye and can be frequently found in nature – think about the branches of a tree, and how each is like a miniature tree with sub-branches of its own. Fractals are also a useful concept for solving mathematical problems. "Fractals often appear in mathematical problems where an object can be broken up into several pieces that are similar to but smaller than the original object," says Dan.

The Tower of Hanoi is an elegant example of this fractal representation. Researchers in the 1980s noticed that when you graphically represent the steps within a Tower of Hanoi puzzle of any number of discs, you end up with something resembling a well-known fractal first described in 1915 for unrelated reasons: the Sierpiński triangle. (You can see the resemblance for yourself below or in this animation, here: <http://math.ucdavis.edu/~romik/downloads/hanoi-animation.gif>)



SOLVING THE TOWER OF HANOI THROUGH RECURSION

To move the N discs from pole A to pole B with the help of pole C, start by moving the top $N-1$ discs from pole A to pole C (the recursive bit that uses the same algorithm applied to a smaller number of discs; then move the largest disc from pole A to pole B; and then move the smallest $N-1$ discs from pole C to pole B (a second repetition of the recursive bit).

For an animation that shows this recursive solution in action, visit:

<https://www.math.ucdavis.edu/~romik/tower-of-hanoi/>

“Mathematics is about discovering patterns in the world around us,” says Dan. “The most interesting sorts of patterns to discover are those that reveal that two concepts are related to each other, when beforehand no link between them was known. That’s when you know you’ve hit on a genuinely new idea.”

SHORTEST PATHS

Solving the Tower of Hanoi puzzle is tantamount to finding a shortest path in the graph between the ‘11...1’ state and the ‘33...3’ state. If someone hands you the puzzle after scrambling it to some weird configuration and asks you to bring it to some desired final state, you can do this by tracing out a shortest path in the graph between the sequences corresponding to the starting and ending states (see the figure on this page).

Dan’s inspiration to work on the Tower came after reading about the work of mathematician Andreas Hinz, who worked out a formula describing the average number of steps to get from one random configuration of the puzzle to another – that is, the average length of a shortest path connecting two random states of the puzzle. While in the worst possible case the number of steps would be $2^N - 1$ (which happens when both the initial and final states have all the discs concentrated on one pole, as in the original problem), Hinz’s formula says that for general initial and final states, the number of steps required would be, on average, only 466/885 times 2^N , or approximately 52.6% the number of steps of the worst case. (N is the number of discs). “I was intrigued by the weirdness of Hinz’s formula and the appearance of the strange number 466/885, and decided to look at Hinz’s paper describing his ideas,” says Dan. “When I did and tried

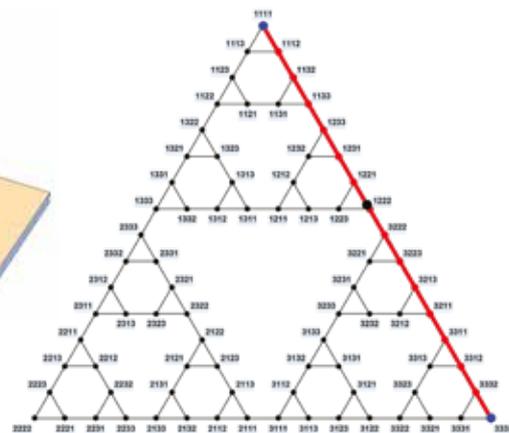
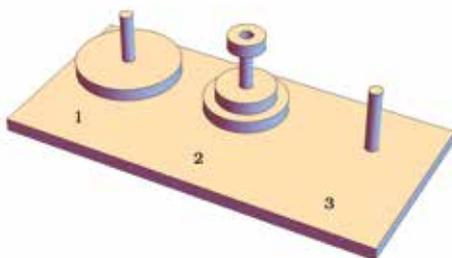
to understand his calculation, I realised I could improve on it in a small way and get a better understanding of where the number 466/885 comes from, and ended up writing my own paper on the subject. It was essentially a chance discovery driven by nothing more than curiosity.”

The idea of shortest paths is very satisfying, but what do these paths mean for the real world? “The Tower of Hanoi graph is a bit too artificial to be of much practical use,” says Dan. “However, shortest paths in general are enormously important these days.” For instance, when we use a SatNav, the SatNav’s software is literally finding a shortest path between two points in a graph. Shortest path algorithms are used by companies like UPS and Amazon to send packages in the most efficient way and by internet providers to route the text messages you send to your

friends at a minimal cost – and in many other situations.

A GATEWAY TO MATHEMATICAL CONCEPTS

The Tower of Hanoi may not appear to have much real-world application, but it is beautiful, somewhat mysterious, and, as it happens, also acts as a gateway to a lot of extremely useful mathematical concepts – recursion, graphical representation and fractals among them. “Pure mathematics sometimes seems like it’s about the pursuit of knowledge that’s fun but useless, but it’s important to allow yourself to follow your curiosity,” says Dan. “There are many examples where major discoveries were made by mathematicians thinking about topics that might have appeared frivolous or self-indulgent. Following their curiosity meant that the world was made richer through cool discoveries.”



The Tower of Hanoi is an elegant example of a fractal representation. Researchers noticed that when you graphically represent the steps within a Tower of Hanoi puzzle of any number of discs, you end up with something resembling a Sierpiński triangle.

HOW TO BECOME A MATHEMATICIAN

- As well as academia, there are many organisations that offer mathematics-based apprenticeships or internships. Examples include Microsoft, NASA and MathWorks.
- According to Indeed, the average annual salary for a mathematician in the US is around \$93k.

PATHWAY FROM SCHOOL TO MATHEMATICIAN

Unsurprisingly, mathematics (and further mathematics, if available) is the most useful subject to study at school to go on to a degree in mathematics. Other useful subjects are physics, chemistry, biology and computer programming. While not generally required, also taking a humanities subject can help broaden your skillset.

A degree in mathematics can open doors to a huge and growing range of careers. Many computer programmers, analysts, economists, software developers and data scientists come from mathematical backgrounds, to name a few.



USING AI AND COMPUTER SCIENCE AS A FORCE FOR SOCIAL GOOD

PROFESSOR ZHIGANG ZHU IS A COMPUTER SCIENTIST BASED AT THE CITY COLLEGE OF NEW YORK IN THE US. HE AND HIS COLLABORATORS HAVE ESTABLISHED THE SAT-HUB PROJECT, WHICH AIMS TO PROVIDE BETTER LOCATION-AWARE SERVICES TO UNDERSERVED POPULATIONS WITH MINIMAL INFRASTRUCTURE CHANGES

TALK LIKE A COMPUTER SCIENTIST

ASSISTIVE TECHNOLOGY – assistive, adaptive, and rehabilitative devices for people with a disability or the elderly population

ARTIFICIAL INTELLIGENCE – intelligence demonstrated by machines

ETHICAL – relating to whether something is morally acceptable

LIDAR – a method for determining ranges by targeting an object with a laser and measuring the time for the reflected light to return to the receiver

GPS (GLOBAL POSITIONING SYSTEM) – a global navigation satellite system that provides location, velocity and time synchronisation

AUGMENTED REALITY – an interactive experience of a real-world environment where the objects that reside in the real world are enhanced by computer-generated perceptual information

For those of us without visual impairment, it is easy to take everyday tasks for granted. When we walk around our local town or village, moving from A to B is straightforward; equally, when we navigate our homes, walking between rooms or floors is a task that we perform almost without thought. However, for blind or visually impaired (BVI) people, moving through indoor environments is not as simple or straightforward.

The World Health Organisation estimates that at least 2.2 billion people have a vision impairment. Of these, more than 285 million people have low vision and over 39 million people are blind. Indoor navigation tools do exist to assist these people, but, typically, these tools have been designed for use by autonomous robots. When robots move around inside a space, they use sensors and other technologies to determine where there is a wall, barrier or step. This information is relayed to the robot and it can change course or position.

However, in recent times, researchers have started to look at how these solutions might be used or modified to assist BVI people, similar to how GPS systems work for outdoor

navigation. The hope is that BVI people will be better able to navigate indoors and overcome some of the challenges associated with visual impairment. Professor Zhigang Zhu is a computer scientist based at the City College of New York. His work is focused on the development of a Smart and Accessible Transportation Hub (SAT-Hub) for Assistive Navigation and Facility Management. One of the areas of focus is to help BVI people navigate an environment with a smartphone and without the need for additional hardware devices.

THE APP

Chief among the innovations that Zhigang has worked on is the Assistive Sensor Solutions for Independent and Safe Travel (ASSIST) of Blind and Visually Impaired People. The team has developed two ASSIST app prototypes. “The first app is based on a 3D sensor called Tango on an Android phone, while the second app is simply based on the onboard camera on an iPhone,” explains Zhigang. “We used the Augmented Reality (AR) features of both types of phones for 3D modelling, but the key features of our apps are the fast modelling of a large-scale indoor environment without much special training for a modeller, a client-server



architecture that allows the modelling to scale up, a hybrid sensor solution for accurate real-time indoor positioning, and, finally (and probably most importantly), a personalised route-planning method and customised user interfaces tailored to the needs of various users with travelling challenges.”

ROUTE PLANNING

The ASSIST app uses both Bluetooth low energy (BLE) beacons to inform users which region they are in and the on-board camera to track their locations accurately and in real-time. Incredibly, the algorithms that the route planner uses can take information from 3D models of an environment, including landmarks, whether there is data connectivity in a location, the crowd density of a particular area, whether any building or construction works are taking place, or other personal user preferences, such as whether they require stairs or elevators. This information is pooled together and then considered by the app to provide the best route for each specific user.

OTHER USERS

The team has also considered people with Autism Spectrum Disorder (ASD), where the crowd density feature is particularly useful. Understanding how busy any given area is can be useful to everyone using the technology the team has developed, but people with ASD often struggle with large crowds, so this feature is especially important for them.

TESTING

The team has tested the SAT-Hub solutions with both BVI and ASD users. “The first step was to hold focus group studies with users. Fortunately, we have user study experts on our team (Cecilia Feeley at Rutgers for Autism Transportation, Celina M. Cavalluzzi at Goodwill NY/NJ for ASD training, and Bill Seiple at Lighthouse Guild for BVI services),” says Zhigang. “Secondly, we modelled the

headquarters of Lighthouse Guild and ran test routes with our users. Eventually, our goal is to install the system in a transportation centre for a larger scale test.”

CHALLENGES

There are ethical issues and privacy concerns relating to the potential intrusive nature of the sensors and cameras used to help users. The team is mindful of this and aims to provide users with unobtrusive and inclusive interfaces with universal design principles. “Since onboard sensors and cameras are used as users’ ‘eyes’ and surveillance cameras are used for crowd analysis, ethical and privacy concerns need to be addressed,” explains Zhigang. “Our human subject studies are approved by the Institutional Review Board (IRB) of the City College of New York.”

There are technical challenges relating to making the ASSIST apps from an augmented reality (AR) tool work in a small area, through to a robust and real-time application that can be scaled up to a much larger area, such as a campus or even an entire city. There is also the challenge of ensuring user interfaces are personalised for different groups. To overcome these problems, the team is focused on performing cross-disciplinary collaborations across industry, academia and government.

A TEAM EFFORT

The team consists of experts in AI/machine learning (Zhigang Zhu at City College of New York, Hao Tang at Borough of Manhattan Community College), facility modelling and visualisation (Jie Gong at Rutgers – Co-Lead of the SAT-Hub Project, Huy Vo at City College of New York), urban transportation management and user behaviours (Cecilia Feeley at Rutgers, Bill Seiple at Lighthouse Guild), customer discovery (Arber Ruci at City University New York), and industrial partnerships (Zheng Yi Wu at Bentley Systems,



PROFESSOR ZHIGANG ZHU

Herbert G. Kayser Professor of Computer Science, The Grove School of Engineering, The City College of New York and The CUNY Graduate Center USA

FIELD OF RESEARCH

Computer Science

RESEARCH PROJECT

Using AI for social good – transforming a large transportation hub into a smart and accessible hub to serve people with transportation challenges, such as passengers with visual or mobility impairment

FUNDERS

US National Science Foundation, US Office of the Director of National Intelligence (ODNI) via Intelligence Community Center for Academic Excellence (IC CAE) at Rutgers, US Department of Homeland Security (DHS), Bentley Systems, Inc.

Inc.). More importantly, many talent students at various stages of their studies (from high school to college to master to PhD) are contributing to and making ideas reality.

THE NEXT STEPS

The Co-Principal Investigator, Arber Ruci, is leading a team on an NSF I-Corps training course to bring the ASSIST technology to market. Jin Chen began her research in Zhigang’s lab during her sophomore year and is the entrepreneurial lead of the I-Corps team. The project is an integration of security, transportation and assistance and the goal is to develop a solution for a safe, efficient and enjoyable travelling experience for all. The new development of the navigation app, iASSIST, works with a regular on-board camera of an iPhone to perform similar functions as the 3D sensor of the ASSIST app.

ABOUT COMPUTER SCIENCE

Computer science pervades almost every area of our lives in some way. Ever since Charles Babbage first described what he called his 'Analytical Engine' in 1837, the science of computing has been developing, and impacting our lives.

As with anything that leads humanity and society into uncharted territory, there are ethical concerns about what developments in the field of computer science and AI could lead to. However, Zhigang and his team's work shows that computer science and AI can be used as a force for good.

Zhigang chose computer science as his major in college after his high school teacher told him in the 1980s that computing would be at the frontier of the 20th and 21st century. "In the early stage of my career, I was mostly motivated to pursue innovative and cutting-edge research, so I entered into the field of AI and computer vision," says Zhigang. "More and more, I felt a distinctive calling to use AI and assistive technologies to improve the quality of life for people, especially those who are mentally or physically challenged.

Zhigang believes that, managed correctly, AI can be used for social good. "I am working

on assistive technologies to help people who are blind or visually impaired, or with ASD, among other conditions," explains Zhigang. "However, AI for social good can be used in many more applications, solving health, humanitarian and environmental challenges."

As Zhigang's research shows, AI and computer science can lead to significant improvements in the lives of visually impaired people, as well as ASD users. If you want to make a real positive difference to people's lives, computer science could be the path for you, especially as technology and its potential applications continue to grow.

EXPLORE A CAREER IN COMPUTER SCIENCE

- Zhigang recommends the *Association for Computing Machinery's* website as a major source of important information for those interested in research and education within the field: <https://www.acm.org/>
- The *IEEE Computer Society* website contains a wealth of information: <https://www.computer.org/>
- The average salary for a computer scientist in the United States is \$106,000, depending on the level of experience: <https://www.indeed.com/career/computer-scientist/salaries>

PATHWAY FROM SCHOOL TO COMPUTER SCIENCE

Zhigang is a firm believer in studying many different branches of mathematics throughout your schooling and college to give you the breadth of understanding necessary for a career in computer science and data science. He also advocates achieving a solid background in critical thinking to ensure you can keep up with the pace of change that is a hallmark of the field.

<https://www.prospects.ac.uk/careers-advice/what-can-i-do-with-my-degree/computer-science>

HOW DID ZHIGANG BECOME A COMPUTER SCIENTIST?

I was interested in reading as a child. The materials were scarce in the rural area where I grew up, but I read whatever I could find and tried to connect the dots.

Becoming a scientist was a call to service. When I was young, we were behind in science and technology in the country I grew up in, so I thought doing science and technology, especially computer science, was something I should dive into to make a contribution.

Purpose has made me successful. It doesn't necessarily have to result in a career or fame, but having a sense of doing something good, in whatever capacity I have, motivates me. I have also maintained a certain level of curiosity in discovery and do not give up easily.

If I fail in one thing, I might pick two more interesting things to pursue – it is important to be doing something meaningful and enjoyable instead of regretting what I failed at. My personal faith also helps me to overcome

obstacles by tuning myself to higher callings.

I will never regret switching from autonomous robotics to assistive technology in order to help people in need, even though I have to learn a lot of new things, collaborate with people from different fields and, in some sense, be willing to perform certain degrees of services. I made sincere friends – both collaborators and users – who truly appreciate and understand each other.

MEET JIN CHEN



Jin Chen is a Graduate Research Assistant who worked on the SAT-Hub project as a student and is now leading a project to bring SAT-Hub to the market.

I am the leading developer of the ASSIST app in the IOS version. I implemented the app using the techniques we developed in our research, including hybrid modelling and a transition method for real-time indoor positioning without delays. I developed and tested the landmark extraction method and personalised route planning method, and designed the customised user interfaces with my colleague, Lei Zhang. I am the Entrepreneurial Lead of the NSF Innovation Corps (I-Corps) team, where I focus on investigating the commercial path for our innovation. This includes understanding customer segments and marketing opportunities for our technology through discussion with people from various fields.

Working on this project as a student improved my communication skills and taught me how to talk to people from different backgrounds. I had the opportunity to work with experts

from different fields and understand their perspectives – from both business and technical points of view. I also expanded my technical knowledge in computer vision and software development.

Leading a project, the most important thing is to have a business mindset and maintain good communication with the team. Our team is great at keeping everyone updated, with flexible weekly meeting times and organised task tracking. I have learned to adapt to the rapid changes and adjust our tasks based on new requests. I have also learned new business language and how best to develop our technology from a business perspective.

Our goal is to help people travel safely and independently in an unfamiliar environment, especially people with disabilities. In order to bring this technology to market, we also need to consider what benefits we can bring to business, so we can attract investment in our technology. The major challenge is to determine the relationship between ourselves and investors and how to make it a profitable venture.

The technology proved its success in accurate real-time user localisation and helped navigate the user to their destination based on their needs. Now, we are discovering the connection between our technology and the market. Once we discover the use case for our application, we will perform a series of tests and find partners for our business. This customer discovery journey should take several months. If everything goes according to plan, our application will be on the market within the next year or two.

Our I-Corps team wants to expand the ASSIST app into a digital twin application that will integrate the IoT sensors, cloud computing and analytic models for collecting and analysing real-time data, such as visitors' locations and traffic information. These data can help provide better navigation experience for visitors and help businesses manage and operate their facilities. We aim to explore our digital market entry point during the I-Corps training and find the best use case for our application and our business model.

ZHIGANG'S TOP TIPS

- 01** For computer science and data science, you will need to have a solid foundation in maths, from theory through to applications, so keep this in mind throughout your studies and choose your modules wisely!
- 02** If you do something you love, motivation comes far more naturally – and motivation is essential for conducting research across your career!
- 03** Computer science programmes have specific course requirements, but there are subjects I consider fundamental: calculus, linear algebra, data structures and algorithms.



USING COMPUTER SCIENCE TO ASSIST IN CREATING AN ULTRA-CLEAN SCIENTIFIC LAB ENVIRONMENT

PROFESSOR KLARA NAHRSTEDT, OF THE UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN, USA, LEADS THE SENSELET PROJECT, WHICH IS DESIGNED TO MONITOR, PREDICT AND INFORM USERS ABOUT MICRO-CLIMATE IN CLEANROOM ENVIRONMENTS. THE PROJECT ENABLES SAFE RESEARCH ABOUT MATERIALS AND SEMICONDUCTOR CHIPS IN ACADEMIC SCIENTIFIC LABORATORIES

For some, being asked to ‘clean your room’ will be a familiar request. Perhaps you will put books on a shelf, make your bed, move dirty clothes to the wash basket and take empty mugs to the kitchen. While that would no doubt please many, there are scientists working in cleanrooms that would make any room in any house look positively filthy!

When new technology and new products using sensitive materials are being designed and developed, it is essential that the environment is clean – really clean. Clean to the extent that there is not even a mote of dust flying in the air. One product that requires such an environment is semiconductor devices, which are used in a wide range of electronics, such as computer chips in laptops, personal computers and smartphones. Hence, these semiconductor devices are an essential requirement for modern life – you (and everyone you know) use them every day, even if you do not know it.

But think of how difficult it is to create a space where not even dust can get inside. It is with this aim that Professor Klara Nahrstedt, of the Computer Science Department at the University of Illinois, Urbana-Champaign, has embarked on her current project. Klara

and her team from the Coordinated Science Laboratory (CSL) (graduate students Zhe Yang and Beitong Tian) and Holonyak Micro-and-Nanotechnology Laboratory (HMNTL) (graduate students Patrick Su and Robert Kaufman, principal research engineer Dr Mark McCollum, and Electrical and Computer Engineering Professor John Dallesasse) formed the project entitled Sensory Network infrastructure for Scientific Lab Environments (SENSELET). The aim is to assist scientists in maintaining environmental control within cleanroom labs to fabricate new materials and semiconductor chips.

WHY ARE CLEANROOMS SO IMPORTANT?

If a mote of dust lands on a TV screen it hardly matters; the screen is so big that a dust particle is inconsequential. However, the experimental structures of devices in cleanrooms that the SENSELET project monitors are made on the micron to nanometre scale. A nanometre is one billionth of a metre, which means that the structures of these devices are often smaller than a single dust particle and can ruin the manufacturing process of these devices – this comes at an economic cost, but it can also lead to semiconductor chip failures and significant

delays in semiconductor research. Cleanrooms help prevent this from happening by constantly filtering the air throughout the room to ensure there is virtually no dust or particles.

It is not only problems with dust that Klara and her team are working to overcome. There are other environmental parameters, such as temperature and humidity, that must be strictly controlled. This is particularly important for polymers (materials made of long, repeating chains of molecules) such as photoresist, which is a light-sensitive material that is part of a crucial process in the electronics industry. If the temperature and humidity are not kept within certain parameters, they can result in the device having different dimensions from those required, causing the device to fail and, ultimately, the whole chip to fail.

HOW IS SENSELET HELPING TO ENSURE THAT CLEANROOMS ARE EFFECTIVE?

Steps can be taken to try and ensure that the cleanrooms in which specific devices are being built operate properly. However, it is necessary to continuously monitor the room’s environment to discover whether the required



**PROFESSOR
KLARA NAHRSTEDT**

Grainger Distinguished Chair in Engineering Professor, Computer Science Department, University of Illinois at Urbana-Champaign, USA

FIELD OF RESEARCH

Computer Science

RESEARCH PROJECT

Developing an affordable sensing infrastructure called SENSELET that can be used in academic cleanrooms. The outputs ensure researchers can maintain a pristine environment that is perfectly suited to creating, building and developing extremely important materials and devices for future computing technologies.

FUNDER

This work was supported by the National Science Foundation (NSF) under the award number 1827126. The contents are solely the responsibility of the authors and do not necessarily represent the official view of NSF

conditions are being maintained. Klara and her team have put their computer science knowledge to use to build SENSELET, which can collect and track data automatically, thereby ensuring researchers can monitor and predict the environmental behaviour around scientific equipment (e.g. microscopes) in any given cleanroom. Ultimately, this facilitates a proactive rather than reactive approach and enables researchers to work around the clock without fear of damaging equipment.

WHAT ARE THE MAIN COMPONENTS OF SENSELET?

SENSELET consists of three components. “The first component is the environment monitoring module, which is composed of temperature, humidity, air-flow and water leakage sensors – and a small device we call SenseEdge to collect sensory data and push data to the remote cloud called SenseCloud,” explains Klara. “The second component is the data storage engine residing in the SenseCloud. This module runs a time series database which stores all the sensory data. The third component, residing in the SenseCloud, is the visualisation and alert module, which provides visualisation dashboards to lab administrators and sends out alerts when environmental data exceed a normal range.”

Sensors are deployed in key locations within the cleanroom to monitor the environment. In addition, they sample and track the environmental information over time so that users can access an overview of the cleanroom environmental data on a periodic basis.

WHAT CHALLENGES HAS KLARA FACED DURING THE PROJECT?

The most difficult problem has been reliability,

closely followed by maintenance of sensors. “We do not have the same budget as the semiconductor companies do, so we rely on off-the-shelf commercial sensors which do not have very high reliability guarantees,” says Klara. “In addition, we do not have sufficient staffing to constantly monitor and maintain the sensory hardware and the corresponding sensing services. Hence, we need to build the system as robust as possible. To address this, we designed a watchdog mechanism to manage the sensors.”

Another issue concerns the heterogeneity of sensors, that is, the fact that sensors are of different types. Klara and the team are working to ensure SENSELET supports different sensor types easily and makes it simple to add or replace sensors. The final challenge is related to time-sensitive data analysis – it is essential that SENSELET can trigger warnings at a time that is most beneficial. Klara and the team have been working to shorten the time between the occurrence of an abnormal sensory event and the alert. The aim is to create a system that can predict future abnormal events based on the current situation; the benefits to manufacturers of electronic equipment would be enormous.

WHAT HAVE BEEN THE KEY SUCCESSES OF THE PROJECT?

SENSELET has been used within the University of Illinois, Urbana-Champaign, where Klara is based, and provided quantifiable data showing that the humidity control is not within specifications. The system has also identified other environmental problems across a range of academic scientific locations within the HMNTL. “A dashboard has been created to notify users of the current temperature

and humidity deviations, measured inside the cleanroom, as well as historical data being tracked every minute,” explains Klara. “This data has proved useful in helping cleanroom lab managers and researchers adjust their management and scientific processes. Overall, SENSELET also demonstrated a low-cost, high-performance sensory network capable of micro-climate monitoring and being deployed in academic scientific environments, such as cleanrooms for micro-climate monitoring.”

There is still more work to be done, but SENSELET is already proving its worth – and further advances in the technology will save a tremendous amount of time, effort and money. It is fitting that Klara and her graduate students are putting their computer science expertise to use to enable the materials and semiconductor device fabrication research and development environment that will advance the field of computing!

ABOUT COMPUTER SCIENCE

Computer science is an extraordinarily broad field that has no definitive pathway. Irrespective of whether you want to enter academia to further research in the field, work in industry to realise the applications of technology, or even have a general interest in your spare time, there are some fundamentals and – as with so many sciences – mathematics and physics will stand you in good stead.

Klara is a computer scientist who is currently working on the development of sensory network infrastructure that will help scientists in laboratories research, build, develop and manufacture materials and semiconductor devices that have near-limitless benefits. This pathway should help demonstrate how there is no single route into the field of computer science and that the world really is your oyster with such a broad scientific field. In many ways,

computer science is what you want to make of it!

WHAT DOES KLARA FIND MOST REWARDING AND CHALLENGING ABOUT THE FIELD?

Computer science is extremely rewarding because through it, you are able to acquire knowledge and skills that impact many people in the current digital transformation era. However, it is also challenging! “One has to have patience and perseverance when learning new programming languages, tools, coding frameworks, designing new digital systems under constantly changing hardware and software technologies, and understanding user communities to be easily usable and inclusive for different communities,” explains Klara.

In the future, Klara wants to develop trustworthy, latency-aware and sustainable

large-scale distributed cyber-physical systems that interconnect users and machines and give them extended sensing, decision making, reasoning and actuating capabilities. This will be challenging but, once achieved, very rewarding.

WHAT ISSUES WILL THE NEXT GENERATION OF COMPUTER SCIENTISTS FACE?

Klara thinks there will be several issues, such as the security and privacy of distributed computing technologies; ethical and biases issues when coding digital systems for broad audiences; and the low-cost sustainability of digital technologies over years. “It is not possible to replace smart meters every year like we do with our smartphones,” says Klara. “One of the main challenges for future computer scientists is to find a way of making computer systems that last longer and do not become a security threat.”

EXPLORE A CAREER IN COMPUTER SCIENCE

- [Computerscience.org](https://www.computerscience.org/) is a brilliant resource for anybody considering a career in the field. It is difficult to think of a question or concern you might have that is not covered somewhere on this site:
<https://www.computerscience.org/>
- This article from The Guardian was published almost a decade ago, but the resources it points to are still so useful:
<https://www.theguardian.com/teacher-network/2012/jan/24/top-ten-computer-science-teaching-resources>

PATHWAY FROM SCHOOL TO COMPUTER SCIENCE

Klara recommends taking mathematics, physics and some other science classes to become accustomed to rigorous thinking and reasoning about science and related phenomena. English will always serve you well because communication skills are so important when presenting findings. Klara believes you should also consider learning another language – scientists often need to travel around the world to share knowledge and knowing another language can be handy! You should think about taking simple computer science classes as soon as possible to become well-versed in computational thinking.

Relevant degree subjects include mathematics, computer science and engineering. Computer science is such a broad subject that there are a wide range of routes into the field – it really depends on which direction you want to head after your studies. “There are many aspects of computer science students should try to understand, including distributed systems, networks, operating systems, computer architecture, security, privacy, programming languages and software engineering,” says Klara. “There is also theoretical background, including algorithms, data mining, AI algorithms, control theory, optimisation theory and statistical reasoning.”

<https://www.prospects.ac.uk/careers-advice/what-can-i-do-with-my-degree/computer-science>

<https://www.computerscience.org/careers/>



Dr Mark McCollum (right) in the HMNTL Cleanroom.

HOW DID KLARA BECOME A COMPUTER SCIENTIST?

As a child, I was interested in mathematics, physics, foreign languages, literature and history. As an adult, I continue to be interested in all of these subjects and more!

My parents were a major inspiration throughout my childhood. Also, my mathematics middle-school teacher and my mathematics and physics high-school teachers inspired me to become a scientist. Without all of these, it is difficult to imagine what I might have been doing today!

There are many attributes that I consider have made me successful as a scientist. The first is curiosity – wanting to understand how things work is at the centre of many scientists' motivations and I am no different. There is the need to be patient, because sometimes learning something can take time! I also like to dig deeper into subjects and find reasons behind scientific phenomena (even if none

are forthcoming). Then, there is perseverance that helps me to keep going, even when the solutions to a problem are not immediately obvious. Finally, having respect for other people's expertise and their valuable input is extremely important.

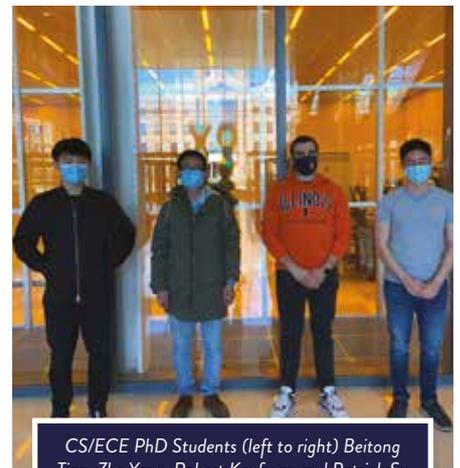
The first step to overcoming obstacles is always working to understand what the cause of the obstacle is. I try to achieve this by analysing the situation if I have the knowledge and means to overcome the challenge but, if not, I will actively ask for help and collaboration from those around me. Then, there is the option of trying to raise funds if the problem is big enough to warrant its own research project!

My proudest career achievements are numerous. I love that I have helped many PhD students and master's students graduate and become highly valuable scientists and

engineers in society. There is also a major element of pride in hearing from former undergraduate students who took my classes and acknowledge that it was my classes that had a positive impact on their professional career. Seeing dancers in places around the world dance together in real time inside joint immersive virtual spaces, created by our tele-immersive project, TEEVE (Teleimmersion for Everybody), was also very rewarding! Next, there is seeing semiconductor researchers in cleanroom laboratories use our data and sensory cyber-infrastructures, such as 4Ceed and SENSELET, for their research that helps them speed up their scientific experiments and gain new insights and knowledge. Finally, seeing many of my research results having an impact throughout the computing industry through my former students, makes everything I do worthwhile.

KLARA'S TOP TIPS

- 01** You will acquire the rigour of learning during your formative years at school and college, but it is important to try and maintain curiosity throughout this period, even when it might seem difficult.
- 02** Be conscious of the different social and technical tools you can learn that will prepare you for solving societal problems; there are many new challenges that will arise from the digital transformation of all disciplines and to overcome these science needs people who have considered the issues.
- 03** The next generation of computer scientists and engineers will need to understand other scientific, engineering and social domains where computing is embedded; learn to speak the languages of other domains; respect others and be willing to work in teams; and have the ethical skills to develop solutions that do not harm others.



CS/ECE PhD Students (left to right) Beitong Tian, Zhe Yang, Robert Kaufman and Patrick Su outside the HMNTL Cleanroom.



MEET THE TEENAGER INVESTIGATING PLASTIC- EATING ENZYMES

KREESHA SAHA IS 16 YEARS OLD AND ALREADY HAS A SCIENTIFIC PAPER UNDER REVIEW. SHE TELLS US ABOUT HER RESEARCH INTO HOW ENZYMES MIGHT BE ABLE TO BREAK DOWN PLASTICS AS WELL AS OTHER IMPRESSIVE ACHIEVEMENTS

ADVANCED PLACEMENT (AP) COURSES (COLLEGE-LEVEL CURRICULA AND EXAMS FOR HIGH-SCHOOL STUDENTS)

- BC calculus
- Biology
- Macro/microeconomics
- Government

HONOURS, AWARDS AND INTERESTS

- International Science and Engineering Fair (ISEF) National Finalist (2019)
- FIRST Robotics World Qualifier (2019 – Team Award)
- Founder of West Lafayette Public Library Writing Program (2019 - 2020)

TELL US HOW YOU BECAME AN ISEF NATIONAL FINALIST.

When I was 13 and in 9th grade, I used a software program called STELLA to create a systems dynamics model. I modelled a continuous culture system for the enzyme laccase, which comes from the *Trametes versicolor* fungus. I thought laccase might be able to break down PET plastic. [PET or polyethylene terephthalate is widely used for packaging food and beverages.] So, if I took *Trametes versicolor*, grew it in a continuous culture system, extracted the enzyme and mixed it with PET in this system, I wanted to find out how long it would take, and the parameters needed, for the plastic to break down. Essentially, my ISEF project was a model to show the rate at which PET might break down and the parameters needed – and when I qualified for national finalist, I got to present my work at the Fair.

WHERE DID YOU GET THE IDEA FOR THE ISEF PROJECT?

We only have one planet and I want to take care of it. We use so much plastic – I use so much plastic. It's very hard to live without it. I wanted to find a way to break down plastic and I thought of enzymes because they break down a lot of different things. I didn't have the resources to test this theory, but I knew I could do a simulation of this experiment using STELLA. In this way, I could understand the system hypothetically, to see what could happen if I actually did the test.

AT AGE 13, HOW DID YOU KNOW THAT ENZYMES MIGHT BE ABLE TO BREAK DOWN PLASTIC?

My biology classes! I also live near a university, where I can contact professors who are knowledgeable on the subject. If I want to learn something, I'm lucky to have the people around me to help.

YOU HAVE A PAPER UNDER REVIEW. WHAT IS YOUR RESEARCH ABOUT?

My research project is a continuation of my ISEF project. When I modelled laccase in the breakdown of plastic, I realised it wouldn't work. So, I wanted to find an alternative enzyme for breaking down plastic. I'm now investigating an enzyme called PETase and working with Professor Clark Gedney at Purdue University, USA.



Kreasha in a garden



One of Kreasha's crochet designs

YOUR ISEF SIMULATION PROJECT SHOWED THAT LACCASE WOULD NOT WORK. WHAT OTHER CHALLENGES HAVE YOU HAD TO OVERCOME?

A challenge is that I'm inexperienced! I started this project when I was 13 and now, even though I'm taking AP biology, it's not on par with the research I'm doing. I had to take an existing enzyme, PETase, modify it, model it, get a plasmid created by a company called IDT, insert it into *E.coli*, grow it, purify the protein and run reactions with it. I did have some guidance along the way, but I had to figure out a lot of it on my own – and that was difficult.

YOU ARE ALSO A FIRST ROBOTICS WORLD QUALIFIER. CAN YOU TELL US ABOUT THAT?

Every year, FIRST Robotics set a challenge, which means you have to design a robot that can do X, Y and Z, like pick up jewels from a mat or stack up foam blocks to build a wall. Your robot goes in a ring with another robot and completes various tasks. I was in 9th grade at the time and I helped program the robot, while others in our team built it using CAD (computer-aided design). We also had an outreach team, who worked on social media and getting sponsorship, etc. That was a lot of fun!

YOU ARE REALLY ANIMATED ABOUT THIS! WHAT IS IT ABOUT THIS CHALLENGE THAT YOU LIKED?

I really liked working with my team and the tasks we were being asked to do. We also had all these cool resources at our disposal, like CAD. And I liked our mentors, who were college students and very helpful.

LOOKING AT YOUR RESUME, IT IS QUITE HARD TO IMAGINE YOU DOING ANYTHING RELAXING.

I have a good social life as well as getting things done, and I like crocheting. I love fiction, music and film. I cook a lot of the food I eat. One of my dreams is to be able to have a restaurant, and to go around the world and cook stuff. I also want to learn how to tightrope walk.

DO YOU FEEL THERE IS A LOT OF PRESSURE ON YOUR GENERATION TO BE SUCCESSFUL?

I think there is a lot of pressure, yes, but for me personally, I think I perceive pressure differently to a lot of people. I do feel pressure, but I don't take it to heart. At the end of the day, who am I going to spend the rest of my life with? Me! So, above everything else, I value what I want, what I would like to do and the way I feel. I take care of myself, listen to myself and do what I think is right for me.

THE OCEAN'S STORAGE SYSTEM: HOW PLANKTON INFLUENCES CLIMATE CHANGE

THE OCEAN HAS AN INCREDIBLE CAPACITY TO STORE CARBON. IT HAS BEEN ABSORBING ONE THIRD OF HUMANITY'S EMISSIONS OVER THE LAST CENTURY OR TWO, AND ULTIMATELY WILL ABSORB MUCH OF OUR FUTURE EMISSIONS. PHYTOPLANKTON COMMUNITIES PLAY A KEY ROLE IN THE OCEAN CARBON CYCLE, AS CARBON IS REMOVED FROM THE ATMOSPHERE AND TRANSFERRED TO THE DEEP OCEAN FOR LONG-TERM STORAGE. PROFESSOR KATSUMI MATSUMOTO OF THE UNIVERSITY OF MINNESOTA IN THE US USES COMPUTER MODELS TO UNDERSTAND THIS PROCESS, AND WHAT IT MEANS FOR GLOBAL CLIMATE CHANGE

TALK LIKE AN OCEAN BIOGEOCHEMIST

BIOLOGICAL PUMP – the ocean's biologically driven capture and sequestration of carbon from the atmosphere

CARBON CYCLE – the group of processes that involve converting carbon compounds from one form to another, such as photosynthesis, respiration, decay, and combustion

CARBON SEQUESTRATION – the process of capturing and storing atmospheric carbon dioxide

PHOTOSYNTHESIS – the chemical process by which plants convert carbon dioxide, water and light into organic molecules

PHYTOPLANKTON – microscopic marine plants that inhabit the ocean's surface waters

TAXONOMY – the system of classifying organisms

While humanity is busy pumping carbon into the atmosphere, the ocean is busy absorbing it. Carbon dioxide is soluble in seawater, and from here it can enter living organisms. Phytoplankton – microscopic marine plants – live near the ocean's surface and incorporate carbon into their cells via photosynthesis. Through death or other food chain processes, some of this carbon ultimately sinks into the deep ocean where it is stored in seawater and ocean floor sediments. In this way, the ocean acts as a vitally important carbon store, significantly slowing the rate of climate change.

This effect is known as the 'biological pump'. "The biological pump is the vertical transfer of photosynthesis-derived organic matter from the surface ocean to the deep ocean," says Professor Katsumi Matsumoto of the University of Minnesota. "This means that carbon dioxide from the atmosphere is moved to deep waters where it can be sequestered for centuries or more. The stronger the biological pump, the more it cools the global climate through lower atmospheric carbon dioxide."

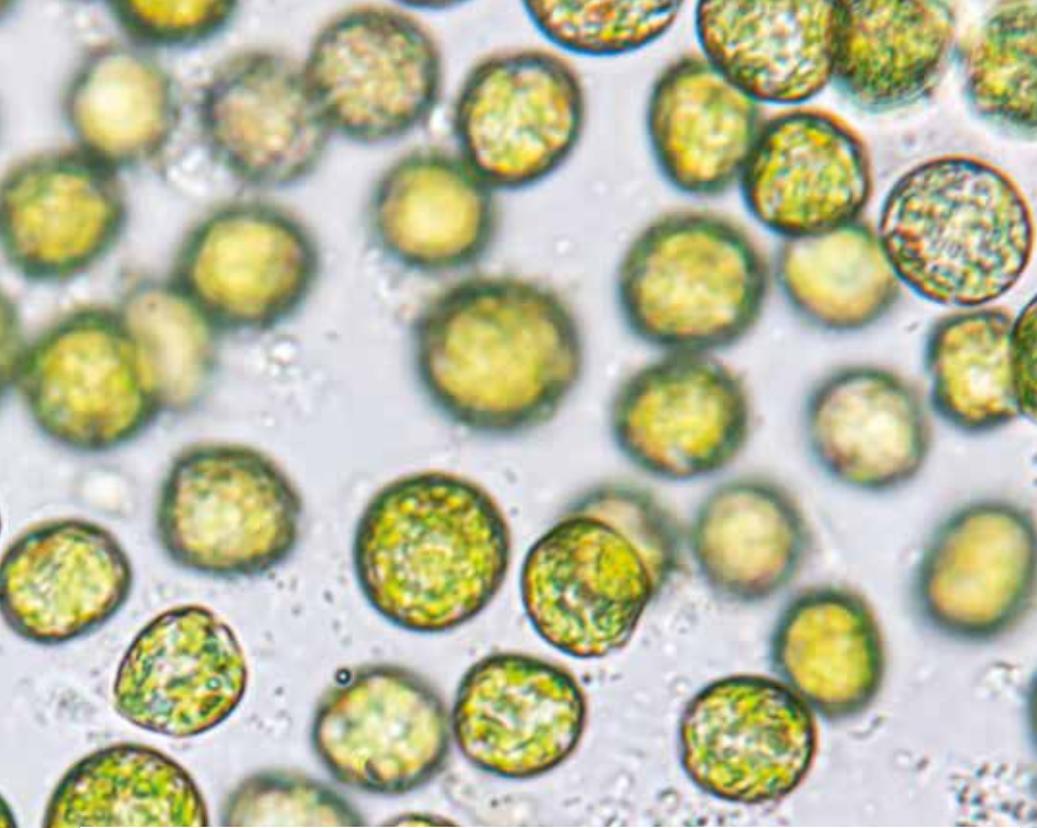
However, the rate at which this happens is partly determined by the phytoplankton communities involved. Depending on

environmental conditions, these phytoplankton communities can vary considerably, which affects their role in the global ocean carbon cycle. Katsumi works in the field of ocean biogeochemistry and uses computer models to predict the growth of these microscopic organisms and their influence on the carbon cycle at the global scale.

PHYTOPLANKTON

"All life forms grow using the same basic elemental ingredients, which include carbon (C), nitrogen (N) and phosphorous (P)," says Katsumi. "Carbon is the basic building block of cells, nitrogen is a major component of proteins, and phosphorous is essential for nucleic acids such as DNA." Katsumi studies the C:N:P ratio of phytoplankton – in other words, how and why the proportions of these three elements vary within these organisms.

This work involves challenging a historical precedent. "Almost a century ago, Alfred Redfield observed that the C:N:P ratio in marine plankton was stable and very similar to the C:N:P ratio of seawater. This observation became known as the 'Redfield ratio' and is a central idea in biological and chemical oceanography," says Katsumi. "However,



**PROFESSOR
KATSUMI MATSUMOTO**

Department of Earth and Environmental
Science, University of Minnesota, USA

FIELD OF RESEARCH

Ocean Biogeochemistry

RESEARCH PROJECT

Modelling how the C:N:P ratio
of ocean phytoplankton varies
depending on different conditions

FUNDER

National Science Foundation

recent work shows that this C:N:P ratio in plankton can actually vary considerably. The goal of my project is to find a way of incorporating this variability into ocean models and use these models to explore the impacts of these variations on the ocean carbon cycle and the global climate.”

INFLUENCES ON THE C:N:P RATIO

“In general terms, the strength of the biological pump is often limited by the availability of nutrients,” says Katsumi. “Just as garden plants grow more when fertilised with N and P, so do marine phytoplankton.” However, research is revealing this is an overly simplistic explanation, because it assumes the C:N:P ratio remains constant and follows the Redfield ratio. Real life, as is often the case, is significantly more complicated.

“My research has identified three broad factors that determine the C:N:P ratio in phytoplankton at different scales,” says Katsumi. “For individual cells, the C:N:P ratio is determined by the availability of N and P, temperature, and light level. For instance, when P is scarce in surrounding seawater, cells will compensate and become C-rich, and use P only frugally.” Yet the plot thickens, because different phytoplankton species respond to these environmental factors in different ways. “Taxonomy is therefore the second broad factor affecting the C:N:P ratio. For example, cyanobacteria are an especially C-rich type of phytoplankton, so communities where these species dominate will have a high C:N:P ratio.” The effects of these different species on the global biological pump depends on how abundant they are across the world – places with a high ‘productivity’ (i.e. lots of phytoplankton present) will make a greater

contribution to the global production than low-productivity areas. “Thus, the three controls are physiological, taxonomic, and productivity,” concludes Katsumi.

BUILDING THE RATIO INTO MODELS

“Numerical models of the ocean are mathematical representations of how the real ocean works,” says Katsumi. “For example, winds will push surface ocean waters and generate ocean currents, and there are equations that express this wind-current relationship.” Physical and chemical processes are generally easier to model, because the fundamental ‘laws’ governing how they work are better understood. Biological processes on the other hand, such as phytoplankton productivity, are more complex and can end up being over-simplified in models. Katsumi is working on changing that. “Many equations of biological processes are based on observations,” he says. “I study the results of observational investigations of ocean biogeochemistry and try to distil them into simple equations, which I then incorporate into my models.”

Currently, the Redfield ratio is used widely to model ocean behaviour such as the carbon cycle, but as has been seen, this isn’t always an accurate representation. Now, oceanographers can use Katsumi’s models within their own models, to give a more true-to-life picture of the global ocean. “My work allows scientists to estimate how the C:N:P ratio of phytoplankton varies according to different environmental conditions,” says Katsumi. “This in turn can lead to more accurate models for estimating what climates were like in the distant past, and the ocean’s responses to current and future climate change.”

DISCOVERIES

Ongoing global warming is leading to an effect in the ocean known as thermal stratification, which means that the ‘layers’ of water at different depths are mixing less than before. Most significantly, this means that nutrients held in deeper layers are less likely to be brought to surface waters, meaning that the phytoplankton’s environment has less N and P available. Based on the Redfield ratio alone, this is expected to significantly weaken the biological pump, because without available N or P, the phytoplankton cannot capture C.

However, Katsumi’s research reveals that this may be partially offset by the other factors he has investigated that affect the C:N:P ratio. “Low nutrient levels elevate the C:N:P ratio in cells, meaning they capture proportionally more C than N or P,” says Katsumi. “At the same time, decreasing nutrients and increasing temperatures favour communities of C-rich phytoplankton species, such as cyanobacteria.” These physiological and taxonomic responses mean that, although the biological pump will still weaken considerably by the end of the century, it could weaken by 30% less than might be expected without this information under a standard future warming scenario.

ABOUT OCEAN BIOGEOCHEMISTRY

Katsumi explains more about his area of research and his career.

WHAT IS OCEAN BIOGEOCHEMISTRY?

Oceanography, the study of oceans, is very broad and interdisciplinary. It encompasses physics (e.g., ocean currents, heat content), chemistry (e.g., elemental concentrations and isotopes in seawater), biology (e.g., biological production, microbial respiration), and geology (e.g., river input, sedimentation). Ocean biogeochemistry is a subset of oceanography that relates to the cycling of important elements on timescales from days to millennia. Because these cycles involve physical, chemical and biological processes, it is naturally interdisciplinary.

WHAT DOES YOUR RESEARCH CAREER ENTAIL?

As a computational chemical oceanographer, I carry out research on wide-ranging topics related broadly to the global ocean carbon cycle and how it links to the global carbon

system. Oceans have a major influence on atmospheric carbon dioxide, which is a main driver of climate change. My research involves working to quantitatively understand the important drivers of the global ocean carbon cycle in past, present and future climates.

WHAT DO YOU FIND REWARDING ABOUT YOUR WORK?

Ocean biogeochemistry is highly relevant to global climate change. The ocean absorbs, and will continue to absorb, much of the carbon dioxide released by burning fossil fuels. Research into areas such as marine phytoplankton and the biological pump are central to understanding how the global carbon cycle works and what this means for the impacts of climate change on the world.

WHAT WILL YOU WORK ON NEXT?

I have two future directions in mind. First, I plan to use satellite data to remotely quantify phytoplankton C:N:P ratios. This would complement my theoretical modelling work with real-world data. Second, I plan to extend

my theoretical work on phytoplankton to incorporate zooplankton. These microscopic animals eat phytoplankton and move vertically through ocean waters, so are an important part of the biological pump and are likely to modify phytoplankton C:N:P ratios as phytoplankton biomass sink.

WHAT ISSUES WILL FACE THE NEXT GENERATION OF OCEAN BIOGEOCHEMISTS?

Breaking down biological processes into quantifiable mechanisms is necessary to model these processes accurately, but this is more challenging for biology than for chemistry and physics. Uncovering the equations behind these processes is key. Another challenge for the next generation is how to process the enormous quantities of data that are collected by remote sensors, such as satellites and autonomous buoys. These datasets will be critical to our understanding, but only if we can make sense of them effectively.

EXPLORE A CAREER IN OCEAN BIOGEOCHEMISTRY

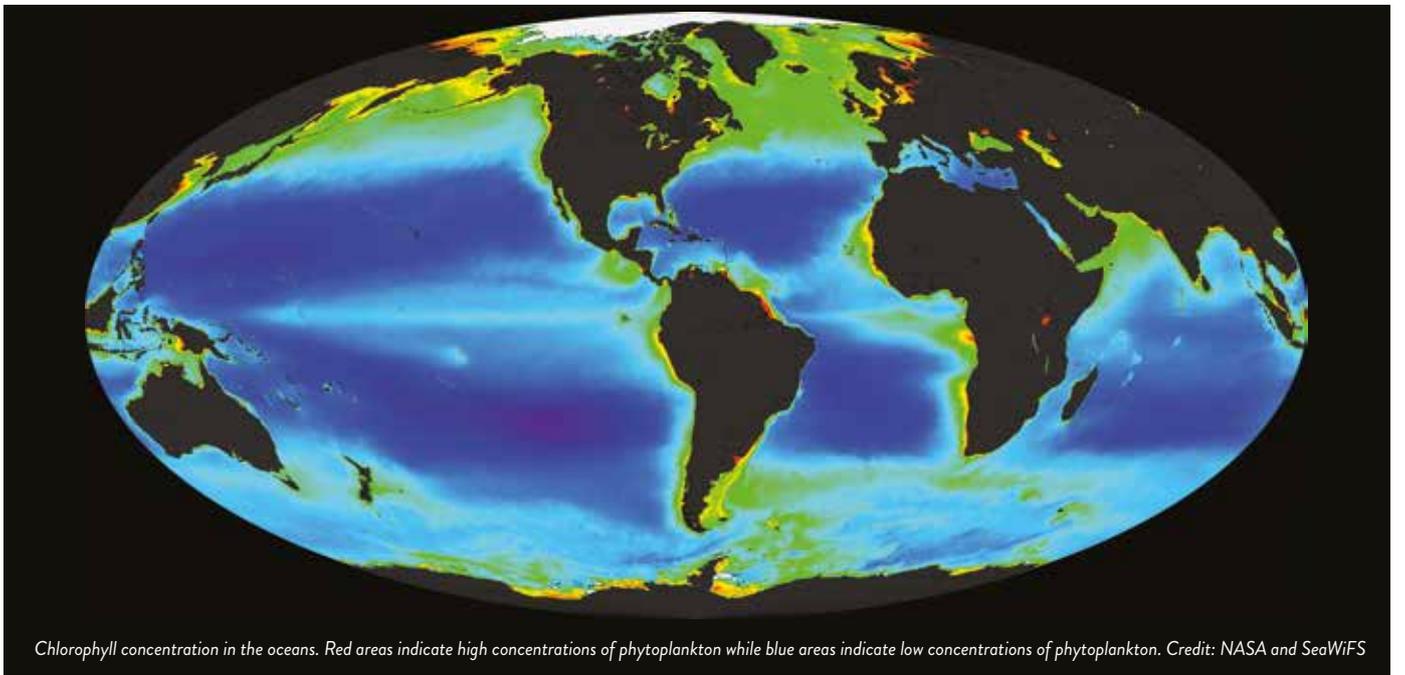
- There are numerous bodies that can support students wishing to study oceanography or related courses. In the US, the NOAA Sea Grant supports students heading towards careers in oceanography, such as through providing scholarships and internships: seagrant.noaa.gov
- The Department of Earth and Environmental Sciences at the University of Minnesota, where Katsumi works, offers regular public outreach programmes (cse.umn.edu/esci/initiatives). Katsumi runs workshops with local high schools most summers, gives public lectures, and welcomes undergraduates to his research group to collaborate on 'bite-size projects'.
- Katsumi says that a career in ocean biogeochemistry is likely to be in academia or governmental research. According to PayScale, the average salary for an oceanographer in the US is around \$70k.

PATHWAY FROM SCHOOL TO OCEAN BIOGEOCHEMIST

Given ocean biogeochemistry's interdisciplinary nature, Katsumi recommends familiarising yourself with the fundamentals of STEM: physics, chemistry, biology and mathematics. At university, courses in oceanography, geochemistry or Earth sciences are highly useful, though many other scientific degrees could also provide the necessary background.

KATSUMI'S TOP TIPS

- 01** Find someone who inspires you and is a good role model.
- 02** Being academically engaged and having an active interest in environmental issues will prepare you well for a career in oceanography.
- 03** Maintain a healthy work-life balance. This is critical for any sustained success in life.



HOW DID KATSUMI BECOME AN OCEAN BIOGEOCHEMIST?

WHAT WERE YOUR INTERESTS AS A CHILD?

I have always been interested in nature. As a young boy, I enjoyed hiking with my family and catching insects with my brothers. As a teenager, I was concerned about environmental protection and conservation.

WHO INSPIRED YOU TO BECOME A SCIENTIST?

None of my family were scientists while I was growing up, so it was not on my radar. Then, my older brother pursued an advanced degree, which opened my eyes to further education. Later, I was inspired by the deep knowledge of my geoscience professors such as Tom Webb

at Brown University and Wally Broecker at Columbia University.

WHAT PERSONAL ATTRIBUTES HAVE MADE YOU A SUCCESSFUL SCIENTIST?

Perseverance is essential. “Genius is 1 percent inspiration and 99 percent perspiration,” as Thomas Edison said, and perseverance has probably been the most important reason for any successes I have had. Luck is often involved too, but you need persistence to get lucky.

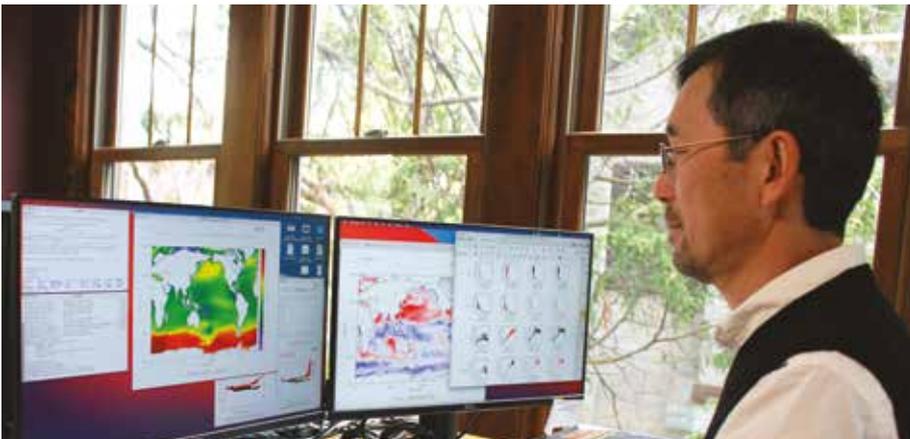
HOW DO YOU OVERCOME OBSTACLES IN YOUR WORK?

Again, through perseverance. I dedicate as much time and effort as I can to a problem,

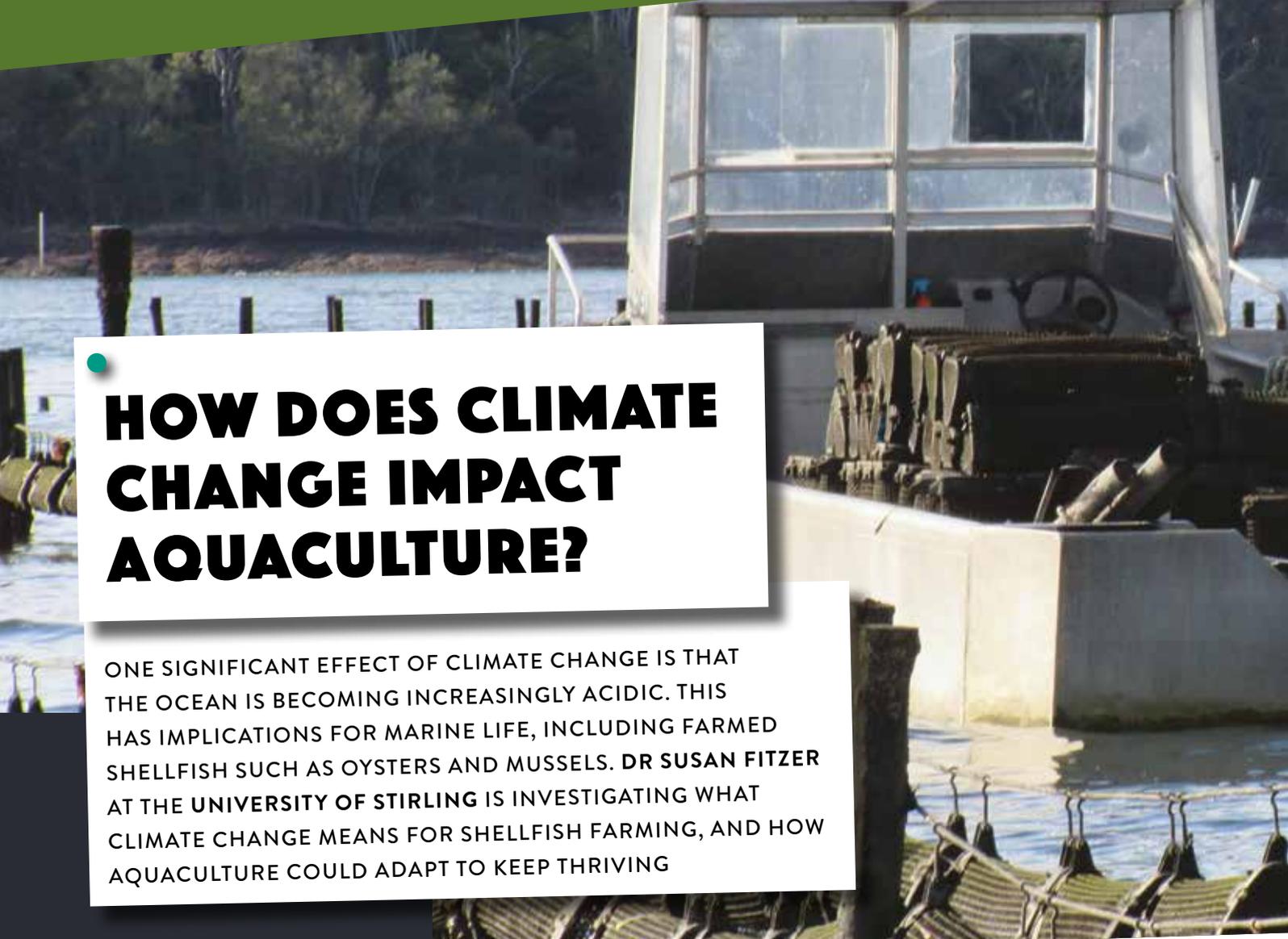
often while learning from others around me. I stop if I feel I have pushed as hard as possible, then come back to the problem after a while. I am often able to overcome obstacles after going through this process a few times, though it may take a while!

WHAT ARE YOUR PROUDEST CAREER ACHIEVEMENTS SO FAR?

I am most proud of the publications led by my students. I also am proud of the opportunities I get as a visiting professor. During past sabbaticals, I have carried out research in Sydney, Hobart, Tokyo and Oxford.



Professor Katsumi Matsumoto remotely logs into supercomputing facilities to model global ocean biogeochemistry.



HOW DOES CLIMATE CHANGE IMPACT AQUACULTURE?

ONE SIGNIFICANT EFFECT OF CLIMATE CHANGE IS THAT THE OCEAN IS BECOMING INCREASINGLY ACIDIC. THIS HAS IMPLICATIONS FOR MARINE LIFE, INCLUDING FARMED SHELLFISH SUCH AS OYSTERS AND MUSSELS. DR SUSAN FITZER AT THE UNIVERSITY OF STIRLING IS INVESTIGATING WHAT CLIMATE CHANGE MEANS FOR SHELLFISH FARMING, AND HOW AQUACULTURE COULD ADAPT TO KEEP THRIVING

TALK LIKE A MARINE BIOLOGIST

AQUACULTURE – the farming of aquatic animals or plants

BIOMINERALISATION – the process by which living organisms produce minerals

BIVALVE – a type of shellfish with a two-part hinged shell, including oysters, mussels and scallops

CARBONATE – an important mineral used to build calcium carbonate shells

HYPERCAPNIA – a build-up of carbon dioxide in the blood

ISOTOPE – forms of the same element with different numbers of neutrons

OCEAN ACIDIFICATION – a reduction in ocean pH, principally caused by the uptake of carbon dioxide

SHELLFISH – a collective term for aquatic shelled species including bivalves, other molluscs and crustaceans

Scotland is a world leader in aquaculture, including the farming of marine bivalves. These farms are found in sea lochs and bays around Scotland's coast, where mussels, oysters and scallops are grown in seawater. Once harvested, the shellfish are sold to restaurants and retailers in the UK, Europe and beyond. Bivalve farming is often considered one of the most sustainable forms of animal protein production, but there are concerns that the industry could be threatened by the effects of climate change.

As more carbon dioxide enters the atmosphere, a significant proportion is absorbed by the ocean. Whilst this helps reduce the effects of global warming, it instead makes the ocean more acidic, which threatens a variety of marine ecosystems and the species that are found in them. This also applies to aquaculture, as shellfish are potentially some of the most vulnerable species to ocean acidification. Dr Susan Fitzer, who works at the University of Stirling's Institute of Aquaculture, is studying the effects of ocean acidification on shellfish to help the aquaculture industry prepare for the future.

OCEAN ACIDIFICATION

Shellfish produce their shells using calcium and carbonate minerals as building blocks. This

process of a living organism producing a non-organic product is known as biomineralisation. "Biomineralisation is used by marine invertebrates such as corals, sea urchins, mussels and oysters to produce protective structures in the form of calcium carbonate shells and skeletons," says Susan. As well as serving a useful biological function, these shells are also important for aquaculture: strong shells lead to greater yields as fewer shellfish are lost to predators or storms, and fewer are damaged in the harvesting and transport process, too.

"Ocean acidification is caused by the ocean uptake of atmospheric carbon dioxide, which dissolves into seawater to form carbonic acid," says Susan. "This reduces the pH of seawater, as well as reducing the carbonate available to produce calcium carbonate shells and skeletons."

Ocean acidification affects shellfish in three main ways:

- **Hypercapnia** is the retention of carbon dioxide in an organism's tissues. For shellfish, hypercapnia leads to reduced shell growth as energy is diverted to metabolic processes that are impacted by this carbon dioxide increase.



- **Reduced carbonate** in the seawater means there are fewer minerals available for shellfish to take up from the environment to build their shells.
- **Acidic conditions** can actively dissolve calcium carbonate shells and skeletons.

“There are two main forms of calcium carbonate shells: aragonite and calcite,” says Susan. “Species can use one or the other, or a mixture of the two.” Research has indicated that aragonite is more affected by ocean acidification than calcite, which means that species that primarily use aragonite are likely more vulnerable.

CARBONATE PATHWAYS

Susan’s lab is investigating how bivalves respond to ocean acidification, in particular how their shell-building process is altered. “Marine animals can source carbonate from several different routes,” she explains. “They can source it directly from seawater; produce hydrogen carbonate through a protein-mediated process; or take carbonate produced from metabolic processes directly from tissues.” Susan collects bivalves from the field and grows mussels and oysters in the lab to see how they respond to seawater of different acidities.

To work out where these bivalves are sourcing their carbonate from, Susan uses stable carbon isotopes (¹²C makes up 98.9% and ¹³C the remaining 1.1% of all carbon). Ratios of these two isotopes can be used to identify movements of the rarer carbon isotope, which often follows the fossil fuel emitted carbon dioxide from the atmosphere into the ocean. These isotopes essentially act as a marker to identify where the carbon in the shell comes from. This means if Susan measures shellfish grown in water with increased carbon dioxide, she can see whether any new shell growth uses carbonate derived

from this environment or from within existing molecules within the organism.

“My research has found that mussels and oysters source carbonate from a metabolic route under favourable conditions, but switch to sourcing from seawater in more acidic conditions,” says Susan. “We additionally discovered that aragonite formation generally has a higher metabolic carbon uptake.” Susan found that this switch also led to reduced shell growth, which is not good news for aquaculture – but there is a silver lining. “Oysters that we had selectively bred for faster shell growth and disease resistance were able to grow larger shells compared to wild oysters in more acidic environments,” she adds. “This suggests that selective breeding could be an important strategy for sustainable shellfish aquaculture to withstand future conditions.”

THE STATE OF PREY

However, given that any lab experiment is by necessity a simplification of the real world, it is possible that this is only part of the story. The ocean is a complex environment, and any one change will lead to a cascade of other changes – not just for shellfish, but also for the organisms they eat, for instance. “Mussels eat micro-algae – tiny single-celled plants,” says Susan. “Increased carbon dioxide in seawater may boost micro-algae growth, since they use carbon dioxide for photosynthesis.” For mussels, this may counteract some of the negative effects of ocean acidification, since they would have more food (and therefore more energy) available.

Susan grew micro-algae in the lab to understand how they respond to different levels of ocean acidification: “I found that when mussels were fed more micro-algae under more acidic conditions, the mussels were



DR SUSAN FITZER

Institute of Aquaculture
University of Stirling, UK

FIELD OF RESEARCH

Marine Biology

RESEARCH PROJECT

Understanding biomineralisation pathways in shellfish to predict the impacts of climate change on aquaculture

FUNDER

Natural Environment Research Council

able to use this food source to continue to grow shells through metabolic routes of carbon uptake.” This is promising, but given the many interacting factors of the marine environment, more research is needed to accurately predict future changes.

BUILDING MUSSEL MASS

“Selective breeding is a promising route for growing larger and stronger mussels and oysters under more acidic conditions in the future,” says Susan. “In future research, I will examine the toughness of mussel shells throughout the harvest and transport process, and whether this will change as the environment changes.”

Susan’s research has resulted in plenty of useful insights for aquaculture. The different responses of aragonite and calcite indicates that different species will likely respond in different ways to ocean acidification, which may lead to changing species or breeding preferences within the aquaculture industry. Her research also indicates that metabolic routes of carbon uptake are preferable for shell growth, and can be promoted through increased concentrations of micro-algae. By modifying aquaculture practices to pre-empt these changes, shellfish farmers can have a head start in adapting to the effects of climate change.



ABOUT MARINE BIOLOGY

Marine biology is the study of the living organisms found in the ocean, and how they interact with one another and their environment. The discipline can also include chemical, physical, and geological oceanography, encompassing the 'whole system' rather than focusing on a particular aspect. Dr Susan Fitzer explains more about her experience of the field.

Marine biology is such an interesting, rewarding and variable career, involving work

in the field and lab rather than the desk all day. I love taking trips to the coast, meeting other researchers and shellfish farmers, and travelling around the world to explore interesting field sites. I have been able to work in some amazing locations while visiting shellfish farms and investigating the challenges that the farmers face.

There are numerous opportunities in the field of marine biology in the UK. Career paths include the roles of research assistant, marine

ecologist, fishery data manager, environmental engineer, marine ecology consultant, and marine policy expert, to name a few. Aside from academia, people with skills in marine biology are often recruited by seafood sector organisations such as Seafish, marine conservation charities such as the Marine Conservation Society, and marine policy actors such as the Scottish Environment Protection Agency or Defra.

EXPLORE A CAREER IN MARINE BIOLOGY

- The Institute of Aquaculture, where Susan works, offers work experience opportunities for schools, such as through Nuffield Research Placements. The Institute also provides talks at career events, local and regional school fairs and at the Stirling Science Festival, which is scheduled to run 14-16 October in 2021.
- For exploring more about what marine biology can entail, Susan recommends looking into the Marine Biological Association, the Challenger Society for Marine Science, and the Marine Conservation Society.
- More details on marine biology careers, including responsibilities, salaries, and working hours, can be found on the Prospects website:

www.prospects.ac.uk/job-profiles/marine-biologist

PATHWAY FROM SCHOOL TO MARINE BIOLOGY

A strong scientific background is advisable for a career in marine biology. At school, this involves taking subjects such as biology, chemistry, maths and physics. Arts subjects can also be a useful supplement for a broader education. At university, undergraduate courses such as biology, marine biology, environmental sciences and biochemistry can all lead to a career in marine biology.



Susan collecting oysters from tray cultivation in New South Wales, Australia.

HOW DID SUSAN BECOME A MARINE BIOLOGIST?

WHAT DID YOU WANT TO BE WHEN YOU WERE YOUNGER?

As a child I was fascinated by the sea and spent many summers exploring tide pools at the seaside. I developed a love for science through doing experiments in my school's labs and taking regular trips to science museums. I'm not sure I always knew I wanted to be a marine scientist, but my interest in marine biology led me to taking a degree in marine biology and oceanography.

WHAT LED YOU TO STUDY THE IMPACTS OF CLIMATE CHANGE ON AQUACULTURE?

I really enjoyed marine chemistry during my degree, and I was interested in climate-induced changes to seawater chemistry and what this meant for marine animals. I explored this further during my PhD, where I researched how ocean acidification can impact zooplankton and implications

for the fish that feed on them. It was during my first postdoctoral research project that I entered the field of aquaculture, when I began working with shellfish farmers to understand the issues they face.

HOW DOES YOUR INTEREST IN BIOGEOCHEMISTRY LINK TO YOUR WORK?

Biogeochemistry is the study of the chemical, physical, geological and biological processes that govern the natural environment. In marine environments, this includes understanding changes to ocean chemistry due to increasing atmospheric carbon dioxide. This directly impacts the biogeological process of marine organism shell growth, so is very relevant for my research.

WHERE DOES YOUR WORK TAKE YOU IN THE WORLD?

I have spent a lot of time both at field sites

collecting samples, and in the lab analysing these samples. This involves a lot of travel – the best part of my job! My first research trip was to Indonesia during my degree, and later in my career I travelled to the Arctic on a research cruise. My current research took me to New South Wales in Australia, where I sampled oysters growing in naturally locally acidic conditions, to provide an insight into how oysters elsewhere might respond to increasing acidification in the future. This also involved working with an oyster breeding programme to find out why some oysters are more resilient, and what this means for future selective breeding.

HOW DO YOU SPEND YOUR SPARE TIME?

I like to explore nature, whether through hill walking, exploring forests or running. In the past, I took part in half marathons and other sport events.

SUSAN'S TOP TIPS

- 01** Scientists question everything. You have to be inquisitive and keen to explore the unexpected.
- 02** As with all careers, there is often competition in the world of marine biology. To break into the field, the key is gaining relevant experience. Look for opportunities to work with conservation societies or citizen science projects, to learn more about the marine environment and simultaneously developing important skills.
- 03** Enthusiasm is key – do what you enjoy!



Susan preparing mussel and oyster tissue powder into tin capsules for isotope analysis in the lab.



Rope cultures of mussels in the UK.

SOLVING A BIOMECHANICAL MYSTERY: HOW JELLYFISH SWIM AND FEED

IN THE PAST, BIOLOGISTS BELIEVED THAT ALL JELLYFISH PROPEL THEMSELVES FORWARD BY RAPIDLY SQUIRTING WATER OUT FROM THEIR PULSATING BELLS. HOWEVER, THIS THEORY DID NOT ENTIRELY MATCH UP WITH THEIR OBSERVATIONS. MARINE BIOLOGIST, DR SEAN COLIN, OF THE ROGER WILLIAMS UNIVERSITY IN THE US, USES A VARIETY OF TECHNIQUES TO SHOW THAT LARGER JELLYFISH USE COMPLETELY DIFFERENT MOTIONS TO SWIM AND FEED. HIS TEAM'S DISCOVERIES TELL US A LOT ABOUT THE LIVES OF THESE FASCINATING ANIMALS

TALK LIKE A MARINE BIOLOGIST

JELLYFISH – a group of primitive invertebrate animals from the phylum Cnidaria, which use pulsating, umbrella-shaped bells to move, and trailing tentacles armed with stinging cells to capture prey and evade predators

CTENOPHORE – similarly primitive gelatinous invertebrates, which use fused cilia (called ctenes) to move and to draw prey to where they can be sensed and captured

BIOMECHANICS – the study of the physical motions and structures used by living organisms

ECOLOGY – the study of the interactions of living organisms with each other and their surrounding habitat

PHYLUM – in biology, the level of classification that ranks above class and below kingdom

SCUBA DIVING – an acronym that stands for 'Self-Contained Underwater Breathing Apparatus', which many biologists use to study ocean ecosystems

JET PROPULSION – when an object rapidly ejects a fluid in one direction, propelling itself in the opposite direction

ROWING PROPULSION – an alternative propulsion mechanism discovered by Sean and his team, where pulsating bells manipulate pressure in the surrounding water

Among all of the creatures in our oceans, few are more ancient or mysterious than jellyfish and ctenophores. First appearing over 500 million years ago, ctenophores swim through water by waving tiny, hair-like protrusions on their cells, named 'cilia.' Jellyfish, also called 'jellies,' evolved at around the same time, but use completely different strategies to move around; in fact, they were the first animals to move using muscle-powered swimming. Incredibly, the muscle layer they use to swim is just one cell thick, making them extremely weak. Because of this, jellies needed to evolve highly efficient ways to propel themselves through water.

Today, all jellyfish do this by contracting their umbrella-shaped bells. In small jellies, this causes water to rapidly squirt out of the bell, generating enough force for them to dart around using jet

propulsion. Previously, biologists thought that all jellyfish swam in this way. However, for animals with bells larger than 5 centimetres in diameter, the water volumes they hold become far too heavy for weak jellyfish muscles to expel them quickly. Dr Sean Colin at the Roger Williams University in Bristol, Rhode Island, US, was first faced with this biomechanical mystery early on in his career and he has studied it extensively ever since.

WHAT TECHNIQUES HAS SEAN'S TEAM USED TO STUDY JELLIES AND CTENOPHORES?

In their earliest studies, Sean and his colleagues used video recordings to study how jellies and ctenophores in captivity interacted with water and prey. Their aim was to study what types and how much food these animals tend to consume,

as well as their wider roles in natural ecosystems. However, because oceans are such complex and intricate environments, the researchers could not be sure that even their most well-designed experiments were entirely realistic.

Since then, Sean's team has explored a variety of different ways to improve observations. These have included cutting-edge techniques in SCUBA diving, and the use of remotely-operated submarines in deeper water – both of which have allowed the researchers to accurately capture the behaviours of wild jellies and ctenophores. They have even worked with a team of engineers to design a robotic jellyfish. By tweaking the design of its bell to efficiently propel itself forwards, they could learn a lot about the real biomechanics used by real jellyfish.



Through these different techniques, Sean's team has now made several ground-breaking discoveries about the differences in biomechanics between large and small jellies.

WHAT HAVE THE RESEARCHERS DISCOVERED ABOUT JELLIES' SWIMMING HABITS?

The shapes of jellyfish bells can vary widely, depending on their sizes. Small jellies have more elongated, torpedo-shaped 'prolate' bells, which help them to jet quickly and efficiently through water. In contrast, larger jellies have flatter, plate-shaped 'oblate' bells. As Sean's team has discovered, these animals have evolved a completely different way of moving around than their smaller cousins.

An oblate jellyfish will start this motion by slowly contracting its bell. This causes the highly flexible circular margin at the bottom of the bell to suddenly bend and flair out, like the skirt of a twirling dancer. This means that the margin acts like a flappy oar: pushing water away from the outer edge of the bell, creating a large region of negative pressure in front of the jellyfish. Finally, the bell will move to compensate for this pressure deficit, and the entire jellyfish is propelled forwards.

Sean and his colleagues have now dubbed this behaviour 'rowing propulsion.' As well as clearly observing the process in wild jellies, they have also shown it to work in a robotic jellyfish – which could only move forwards when a flexible, circular flap was added to its margin. The speed it provides may be slow, but since the motion requires such little muscle power, the researchers

have shown it to be one of the most efficient swimming mechanisms in the animal kingdom.

WHAT DOES THIS TELL US ABOUT THE DIFFERENCES IN FEEDING HABITS BETWEEN CTENOPHORES, AND LARGE AND SMALL JELLIES?

Sean's work has revealed that jellies use jetting and rowing for completely different processes. For smaller animals with prolate bells, an effective hunting strategy is to sit still inside a nutritious water current, with their stinging tentacles extended. When a predator comes along, or if the current becomes depleted of food options, the jellyfish can then rapidly dart away and reposition itself, allowing it to maximise the time spent feeding. This behaviour has had a big impact on the evolution of their tentacles: with the size and type of their prey depending on the spacing between their tentacles, and the number and type of stinging cells they contain.

In contrast, oblate-shaped rowing jellies are moving constantly. They use their own swimming motions to generate nutritious water currents, which they pull and circulate through their tentacles. This means that the capture surfaces have a significant impact on how these jellies interact with the surrounding water. In Semaestomes (an order including Lion's Mane and Sea Nettle jellyfish), long, frilly arms are used to capture large plankton and fish larvae. On the other hand, the order Rhizostomes, which include Cannonball and Barrel jellyfish, do not have tentacles at all. Instead, they use oral feeding disks featuring large clusters of cilia, allowing them to filter for far smaller prey.



DR SEAN COLIN

The Roger Williams University, Bristol, Rhode Island, USA

FIELD OF RESEARCH

Marine Biology

RESEARCH PROJECT

Sean's research centres around the swimming and feeding habits of jellyfish and ctenophores.

FUNDER

National Science Foundation

Ctenophores may have evolved at around the same time as jellyfish, but they use completely different strategies to capture prey. By waving the fused cilia on their bodies, they move water slowly past their sensory structures. This allows them to scan the surrounding water and divert any nutrients towards their tentacles.

WHERE COULD THIS RESEARCH LEAD IN THE FUTURE?

Sean and his colleagues will now continue to study the biomechanics of jellyfish and ctenophores. They will focus on areas including how their shapes relate to their swimming and feeding habits; their roles in ocean ecosystems; and how SCUBA techniques can be used to better study natural environments.

Many areas of research could benefit from these discoveries. Since oblate jellyfish usually have far larger guts than their smaller cousins, they can consume far larger amounts of prey at a time. A better knowledge of their feeding habits could help biologists to better assess their impacts on fragile marine ecosystems, particularly when species are introduced to new areas. Elsewhere, jellyfish and ctenophores could have a lot to teach us about how swimming and flying first evolved in other, more complex animals, and how they manipulate the fluid surrounding them to move.

ABOUT MARINE BIOLOGY

As with other strands of environmental science, what motivates those who work in the field of marine biology is a passion for the natural world and the mysteries it holds, a desire to uncover its secrets and an unflinching commitment to protect it. As Sean's research shows, years of meticulous research provide invaluable insights into the oceans, their ecosystems and the fascinating creatures who inhabit them. Perhaps most importantly, marine biologists – and other environmental scientists – are at the front line of effort to solve the many problems now facing the natural world.

WHAT IS REWARDING ABOUT STUDYING MARINE BIOLOGY?

Marine biologists use a broad range of problem-solving skills to understand how organisms and ocean-based ecosystems function. Researchers then need to figure out how to collect and analyse data, and how to communicate their findings. If a scientist is truly passionate about

their work, each of these steps can be fun and rewarding. A job like Sean's, for example, allows him to develop a diverse variety of skillsets, including teaching, SCUBA diving, videography, computer analysis, and writing.

HOW IMPORTANT IS IT FOR MARINE BIOLOGISTS TO COLLABORATE WITH EACH OTHER?

Since every researcher has their own unique way of seeing the world, collaborating with others as part of a team is an essential part of being an environmental scientist. This can happen in many different ways: Sean, for example, has maintained a close collaboration with his research partner, Dr Jack Costello, since 1990. Together, they have carried out much of their research through close collaboration with small groups of undergraduate students. Working with others with different skillsets in this way enables scientists to complement each other's

expertise. This increases their ability to answer questions, ultimately making their work more productive and enjoyable.

WHAT ARE THE KEY ISSUES FACING THE NEXT GENERATION OF MARINE BIOLOGISTS?

We all know that, due to climate change, Earth's ecosystems are now transforming rapidly – with every organism responding in a different way. This can have far-reaching consequences for natural environments, including our oceans, threatening many species with extinction and altering the natural systems which many people depend on to survive. In the future, environmental scientists will be at the forefront of efforts to understand these changes. It will be their challenge to understand and communicate the changes humans will need to make to ensure the future of Earth's ecosystems.

EXPLORE A CAREER IN MARINE BIOLOGY

- The Roger Williams University offers several outreach schemes. These include a week-long Marine Biology Camp each summer, which gives high school students opportunities to experience research both in the lab and the field:

<https://www.rwu.edu/academics/schools-and-colleges/fssns/departments/biology-marine-biology-environmental-science/marine-biology-camp>

- Check out <https://www.environmentalscience.org/careers> for more information about how to start a career in environmental science, and several university courses currently available in the US.
- Elsewhere, university courses in many subjects related to marine biology and environmental science are widely available worldwide.
- The average annual salary of an environmental scientist in the US is around \$64,000

PATHWAY FROM SCHOOL TO MARINE BIOLOGY

Sean recommends that students should gain a strong foundation in the sciences as a whole. For example, branching into a specific area of environmental science like marine biology would not necessarily involve studying marine biology at college or university. If a student has a strong background in biology, they will be able to specialise more easily in graduate school.

SEAN'S TOP TIPS

- 01** Pursue areas of study that you are truly interested in and enjoy.
- 02** Achieving necessary degrees and having a career in the sciences requires students to endure tough courses and experiences, which are not always fun.
- 03** Achieving success and getting a job requires persistence – and that is much easier to have when you are working for something that you really enjoy.



HOW DID SEAN BECOME A MARINE BIOLOGIST?

WHAT WERE YOUR INTERESTS AS A YOUNGSTER?

I enjoyed sports, being on the water and the outdoors. I always had a particular interest in animals and the water.

HAS THERE BEEN A BOOK THAT HAS MEANT A LOT TO YOU?

There are many books that have shaped my thoughts and inspired me, but one that stands out is *Air and Water: the Biology and Physics of Life's Media* by Mark Denny. It was the first book I read that helped me to understand how physics impacts animal movements and functions.

WHO OR WHAT INSPIRED YOU TO BECOME A SCIENTIST?

I was first inspired to become a scientist on a trip I made to the Bahamas as a child. On that trip, I snorkelled for a week straight

through the coral reefs just off the beach where we were visiting. I think it was that trip that initiated my desire to become a marine scientist.

Since then, I have been repeatedly inspired by other scientists like Jack Costello, who I have collaborated with. Working with scientists who truly love doing science and discovering things about animals has been a continual inspiration throughout my career.

WHAT ATTRIBUTES HAVE MADE YOU SUCCESSFUL AS A SCIENTIST?

I think being observant, persistent, creative, and having a strong intuition about how things work have all been important attributes that have contributed to my success. Observation is the basis of a lot of scientific discovery; persistence and creativity are needed to translate observations into quantitative and

accepted scientific knowledge; and intuition helps to guide your thoughts and efforts.

HOW DO YOU OVERCOME OBSTACLES IN YOUR WORK?

Persistence and creativity are critical to overcome challenges and obstacles. But collaborating with great scientists also helps a lot.

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

I am just proud and thankful that I have been able to have a career (and get paid!) being able to study the scientific questions that I find most fascinating. My main ambition is to do the best science I am capable of doing, so that I can continue to work on these questions for a long, long time.

LOOKING TO THE LIGHT: ASSESSING THE PATH TO SPECIES RECOVERY

ASSESSING SPECIES' RISK OF EXTINCTION IS ESSENTIAL FOR EFFECTIVE CONSERVATION EFFORTS. HOWEVER, THIS ASSESSMENT DOES NOT TELL THE WHOLE STORY – TO UNDERSTAND THE BROADER ECOLOGICAL PICTURE, IT IS ALSO IMPORTANT TO KNOW HOW THE SPECIES IS DOING COMPARED TO PRE-HUMAN INVOLVEMENT. DR MOLLY GRACE OF THE UNIVERSITY OF OXFORD, UK, IS USING A NEW TOOL, THE IUCN GREEN STATUS OF SPECIES, TO ASSESS THIS

TALK LIKE A CONSERVATION SCIENTIST

ECOLOGICAL FUNCTION – the role(s) of a species in an ecosystem. For instance, predators can control prey populations, trees can provide habitats for other species

INDIGENOUS RANGE – the area(s) where a species was found before human influence

IUCN – the International Union for Conservation of Nature is made up of government and civil society organisations and is the global authority on the status of species and the wider natural world

IUCN GREEN STATUS OF SPECIES – a new tool in development by the IUCN that assesses the recovery of species and the success of conservation measures taken for that species

IUCN RED LIST OF THREATENED SPECIES – a tool developed by the IUCN that measures the risk of any particular species going extinct

SPECIES RECOVERY – According to the Green Status, a species is Fully Recovered when it is present, viable, and ecologically functional throughout its indigenous range. Achieving this looks different for each species

The International Union for Conservation of Nature (IUCN) assesses the natural world and advises on measures needed to safeguard it. Their 'Red List of Threatened Species' measures species' risk of extinction and is used by governments and conservationists around the world to guide conservation action. However, the Red List does not tell the whole story.

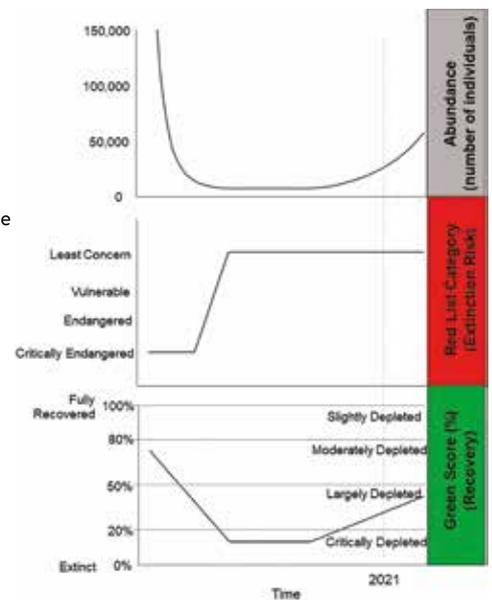
Dr Molly Grace of the University of Oxford is the Task Force Co-Chair for the IUCN Green Status of Species. This new assessment tool focuses on evaluating species' recovery rather than simply avoiding extinction, allowing conservationists to determine how well their efforts are working.

THE GRAY WHALE'S TALE

The charismatic gray whale, found in the Pacific Ocean, is a favourite with whale-watching tours along the west coast of the USA. The species' changing fortunes in recent centuries paint a clear picture of why both the Red List and the Green Status are useful measures of a species' well-being.

Before commercial whaling took off in the 1700s, there were >100,000 gray whales in the Pacific and Atlantic Oceans. Hunting dramatically reduced their numbers – the entire Atlantic population was eradicated and <10,000 individuals remained in the Pacific. Rate of change in population size is a principal metric for the Red List, so the plummeting gray whale population would have resulted in the species being classified as 'Critically Endangered' (if the Red List had been in use then) meaning it was likely to go extinct.

Mounting international concern meant commercial whaling was largely banned in 1949,



How do the Red List and the Green Status assess the Gray Whale differently? Top panel: Gray whales experienced a steep decline in population numbers due to whaling in the past, but eventually the decline stopped, and after a period of time its abundance started to increase. Middle panel: The Red List category of a species measures extinction risk, which is tied to rate of decline. As the rate of decline slowed, the Gray Whale moved to a lower risk category until it was eventually considered Least Concern (LC) because the population stabilised at a relatively high number (more than 10,000 individuals). Once a species is LC, there is no more possible improvement on the Red List. Bottom panel: The Green Status measures recovery using a Green Score, which is measured relative to pre-impact species conditions and so changes at a different rate than the Red List category. This means the LC category is complemented by a low Green Score and the accompanying category Critically Depleted, indicating that even though the species is not in danger of extinction, it is far from recovery. (Note that more information than just abundance is needed to determine the Green Score of a species.)



after which gray whale populations began to stabilise. With a stable population, gray whales were classified as ‘Least Concern’ when the Red List was first implemented, the best classification possible, with no risk of extinction. Gray whale populations have even grown a little since then. “However, the current population size is still much, much smaller than before centuries of whaling,” says Molly. “Scientists might wonder – what is the ecological impact of removing all these whales from the ecosystem?”

This is where the Green Status comes in. By this assessment, gray whales were ‘Critically Depleted’ after whaling ended. Recent increases in their population means they have been upgraded to ‘Largely Depleted’ as their numbers are still significantly lower than in pre-whaling days, despite their Red List classification of ‘Least Concern’. This shows that conservation efforts have been successful, but there is still a long way to go. In fact, the effects of fishing, shipping and loss of sea ice may mean that populations can never return to pre-whaling levels.

ASSIGNING THE GREEN STATUS

“Extinction risk is measured in absolute numbers (if population size has dropped below a certain threshold, or if decline is happening at a certain rate) but recovery is relative,” says Molly. “Assessment of recovery uses several factors:

- Where the species was found prior to major human impacts;
- How much of that historical range the species currently occupies;
- The likelihood of the species continuing to exist in those areas (its viability);
- Whether the species is performing its ecological functions.

Once we have these measurements, a species is assigned a category, ranging from Fully Recovered to Critically Depleted.”

However, assessing these criteria is not simple, as population declines often began before

scientists were recording population sizes. Techniques such as examining genetic diversity in existing populations can be used to estimate past conditions. “Where a species was found at the date when humans began to influence its numbers or distribution is known as its ‘indigenous range’,” says Molly. “If we don’t know when exactly that is, we estimate for 1750, the start of the industrial revolution.”

Scientists divide this indigenous range into spatial units (representing natural divisions within the species, such as subspecies or geographically separate areas of the indigenous range) and assess how the species is doing in each. Often, there are spatial units where the species is now absent, such as the gray whale being extinct in the Atlantic Ocean. “In each spatial unit, we identify whether the species is currently absent, present, viable (not at risk of extinction), or ecologically functional,” explains Molly. “This information is converted into a Green Score. If the species is ecologically functional in all spatial units, the score is 100% and the species is Fully Recovered. If the species is absent in all spatial units, the score is 0% and the species is Extinct (or Extinct in the Wild).”

Scientists also consider the effect that conservation actions have had on a species. “We can estimate what the Green Score would be if no conservation had been done, which can indicate that things would be worse with no conservation efforts.” says Molly.

FINE-TUNING THE GREEN STATUS

To ensure the Green Status provides useful information about species recovery, workshops were run for scientists to discuss how to measure and define ‘recovery’, before testing this on real species. “I worked with over 200 conservation scientists in 38 countries to apply our work to the species they were studying, and improved our methods using their feedback,” says Molly.

Creating a tool that captures complexity but is



DR MOLLY GRACE

Task Force Co-Chair for the IUCN Green Status of Species, Department of Zoology and Wadham College University of Oxford, UK

FIELD OF RESEARCH

Conservation, Ecology

RESEARCH PROJECT

Coordinating the development of the IUCN Green Status of Species, to assess species’ progress towards recovery

FUNDERS

Natural Environment Research Council, re:wild, IUCN Species Survival Commission, University of Oxford

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still usable is no easy task. “One big challenge has been designing the Green Status method to be scientifically rigorous but also user-friendly,” says Molly. “It’s a compromise between making it reflect reality as closely as possible, and actually being understandable!”

GOOD NEWS AND NEXT STEPS

“So far, we’ve tested 123 threatened species from the Red List,” says Molly. “Of those, we estimate that 33 of them (including the California condor, Jamaican rock iguana, and Chinese swamp cypress) would be extinct today if it wasn’t for the hard work and successful actions of conservationists.”

Next, Molly aims to capture enough Green Status assessments to understand global patterns of species recovery, helping scientists to plan future conservation efforts. While the Red List helps conservationists prioritise which species most urgently need conserving, the Green Status points to a brighter future – recovery of species, and ultimately entire ecosystems.

ABOUT CONSERVATION

Conservation is the study of biodiversity loss, and how this loss can be prevented or reversed. Conservation can encompass a broad range of careers; while some conservationists work on the frontlines, collecting species data in the field or engaging governments and communities in conserving biodiversity, others may perform lab experiments or build computer models. Molly's role involves bringing together conservationists around the world to build and test the structure of the IUCN Green Status of Species. She explains more about her career.

WHAT DO YOU FIND MOST REWARDING ABOUT YOUR ROLE?

I really enjoy the opportunity to learn something new every day. Working on the Green Status means that I often dig deep into the histories of species that I sometimes didn't even know existed!

ARE YOU OPTIMISTIC ABOUT THE FUTURE OF CONSERVATION?

I am optimistic, because there is lots of evidence that shows that conservation works to prevent extinction and aid recovery. Over the next few years, I expect that Green Status assessments will provide lots more evidence. While observing declines in nature can be bleak, there is a growing movement called Conservation Optimism which champions conservation success stories.

WHAT ISSUES WILL THE NEXT GENERATION OF CONSERVATIONISTS FACE?

Today, we know that successful conservation must include human needs. 'Old-school' conservation efforts sometimes involved forcibly removing indigenous people from their homes when protected areas were established. Today, community-based conservation efforts

that are inclusive and collaborative are far more sustainable and ethical for both people and nature.

PATHWAY FROM SCHOOL TO CONSERVATION

Unlike research-focused sciences, a career in conservation can often involve the application of research findings as well as research itself. With this in mind, a broader skillset can be useful, though the sciences – especially biology – can provide a core grounding. Maths and statistics are often necessary skills for conservation research. Molly also recommends an understanding of psychology, social science, and history, useful for interpreting people's interactions with nature. At university, degrees or modules in biology, ecology, and environmental science provide a clear path to a career in conservation.

EXPLORE A CAREER IN CONSERVATION

- Practical experience is highly desirable for a career in conservation. Molly emphasises this does not have to be in exotic locations; in the UK, work experience with local nature reserves or organisations such as the RSPB or Wildlife Trusts can be both educational and inspirational.
- Molly recommends the Conservation Careers website for seeking internships in the UK and further afield:
www.conservation-careers.com/conservation-jobs
- The University of Oxford, where Molly works, offers a summer programme for A2 Biology students called the UNIQ Biology course, which gives an insight into the life of an undergraduate biologist at Oxford:
www.uniq.ox.ac.uk/c/biology
- According to Talent.com, the average salary for a conservation scientist in the UK is around £31k.



Gray whale, by jpmckenna, CC BY-NC-ND 2.0

HOW DID MOLLY BECOME A CONSERVATION SCIENTIST?

WHAT WERE YOUR INTERESTS WHEN YOU WERE YOUNGER?

My interest in conservation runs deep. When I was 10, I once spent most of a day performing a conservation translocation of hundreds of tadpoles, as the puddle they lived in was drying out in the summer sun! I have also always had a passion for musical theatre.

WHAT INSPIRED YOU TO BECOME A CONSERVATION SCIENTIST?

When I was an undergraduate, I got a job in a bird cognition lab. I started by cleaning

cages, but over the years I got more involved with the lab's research and eventually designed my own study, which became my first published academic paper. I realised I enjoyed the scientific process – having a question, and then performing experiments to find the answer. It's very satisfying!

WHAT ATTRIBUTES HAVE MADE YOU A SUCCESSFUL SCIENTIST?

For me, the ability to communicate well is extremely important. Every scientist needs to apply for funding for their research, so you need to be able to get different

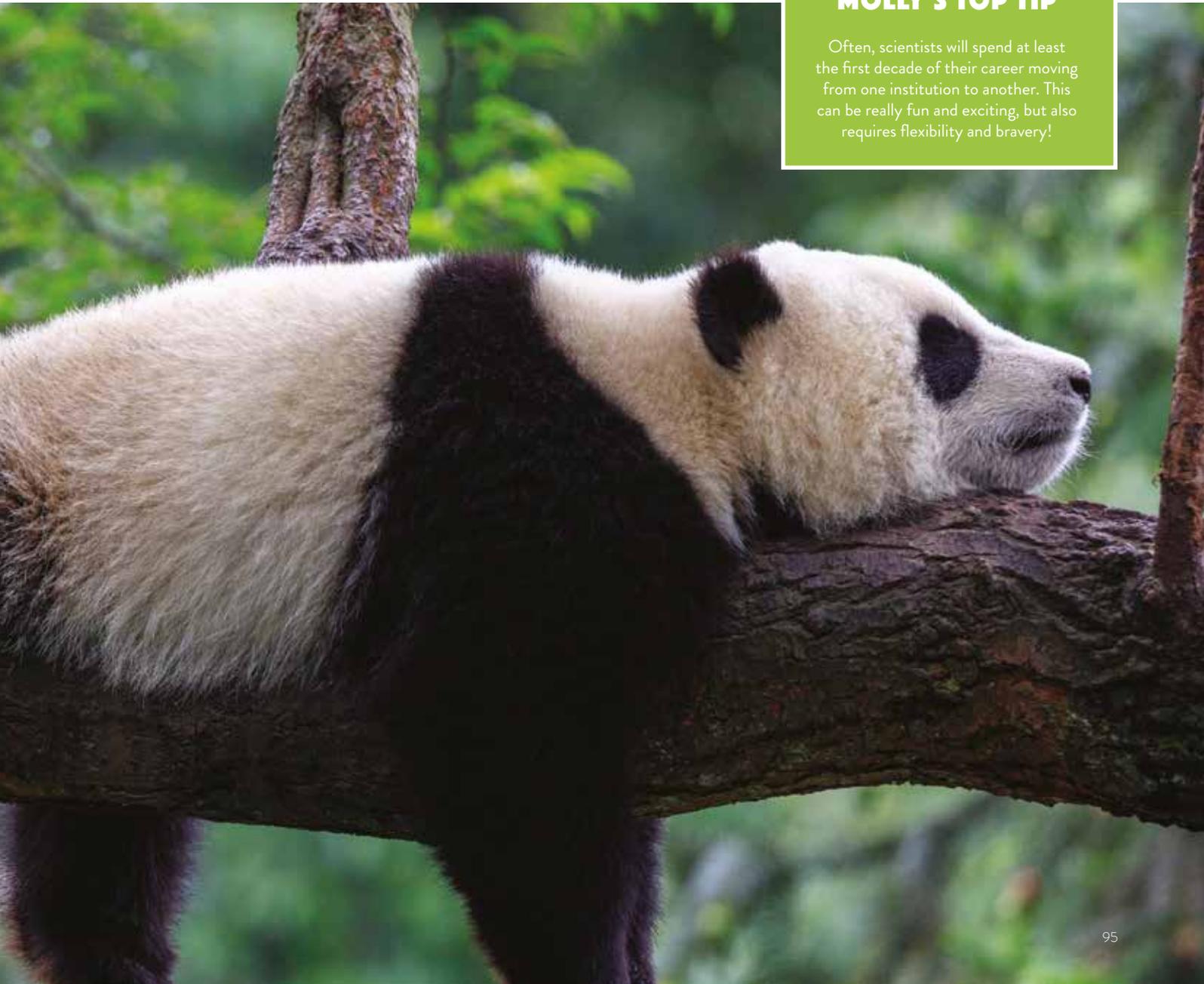
audiences to understand why your work is interesting and important.

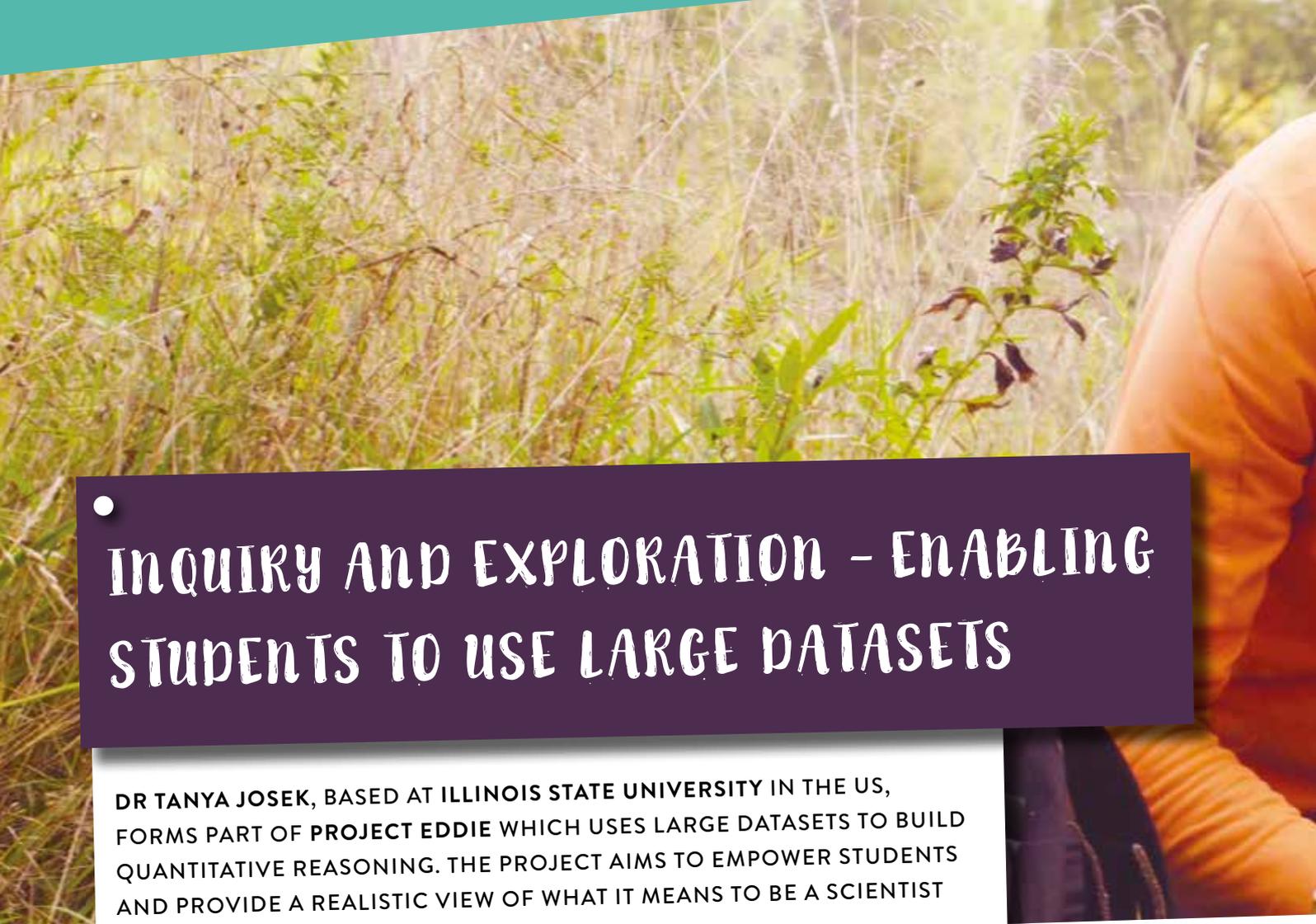
WHAT HAS BEEN YOUR PROUDEST CAREER ACHIEVEMENT SO FAR?

I have just had a paper accepted showing the results for the first batch of Green Status assessments. This paper has 203 authors from all over the world – most scientific papers have less than ten! Leading and co-ordinating that paper was a massive achievement for me, and I'm really proud to share our results with the world.

MOLLY'S TOP TIP

Often, scientists will spend at least the first decade of their career moving from one institution to another. This can be really fun and exciting, but also requires flexibility and bravery!





INQUIRY AND EXPLORATION – ENABLING STUDENTS TO USE LARGE DATASETS

DR TANYA JOSEK, BASED AT ILLINOIS STATE UNIVERSITY IN THE US, FORMS PART OF PROJECT EDDIE WHICH USES LARGE DATASETS TO BUILD QUANTITATIVE REASONING. THE PROJECT AIMS TO EMPOWER STUDENTS AND PROVIDE A REALISTIC VIEW OF WHAT IT MEANS TO BE A SCIENTIST

We live in an age of information, where facts and data on almost any subject are available within a moment's grasp. The vast majority of us continuously carry computers (in the form of smartphones), and a ten-second search grants us access to almost anything we want to know or learn about. Of course, this is not always a good thing – somewhat ironically, so much information creates problems associated with making sense of it all. Then, there are the perils of misinformation, which we see manifest as conspiracy theories and mind-boggling viewpoints.

Still, if we can find ways to navigate our way through the staggering amount of information at our fingertips, there are some genuinely life-changing possibilities. The advent of big data has created the possibility of highly tailored patient treatments, for instance, while the internet serves as a vast forum across which scientists can come together in a quest to improve research and its outcomes. In addition, there is the ushering in of quantitative approaches, where we can measure things as opposed to merely observing them.

It is with the benefits of quantitative reasoning in mind that a group of researchers has

come together to form Project EDDIE (Environmental Data-Driven Inquiry and Exploration). EDDIE is a community of STEM (science, technology, engineering and mathematics) instructors and educational researchers that works to develop flexible classroom modules and resources. Dr Tanya Josek, who is part of the O'Reilly Research Team at Illinois State University in the US, is involved in EDDIE, which enables them to combine their love for entomology (the study of insects) with that of science education.

WHAT IS PROJECT EDDIE AIMING TO ACHIEVE?

The information age has given rise to large, publicly available datasets that can be utilised if the right approaches are taken. The community behind EDDIE works to make use of these datasets to engage students in STEM and improve their quantitative reasoning. "There are a range of teaching modules within Project EDDIE, spanning topics such as ecology, limnology, geology, hydrology, environmental sciences and macrosystems ecology," explains Tanya. "The project also helps build the associated professional development needed to ensure effective use of the teaching modules but, for me, the chief aim is to empower students and give

them a more realistic view of what it is to be a scientist."

WHY IS PROJECT EDDIE NECESSARY?

EDDIE is performing an important role in filling an educational gap. As our ability to collect data improves, the amount of data collected grows. Not all data are of equal use and it can take a vast amount for scientists to draw conclusions that stand up to rigorous scrutiny. Giving students the opportunity to work with real – often enormous – datasets, gives them a greater appreciation for what working with data entails, providing them with the skills, knowledge and experience they will need if they are to become the next generation of scientists.

HOW DID TANYA COME TO BE INVOLVED IN THE PROJECT?

While still in graduate school, Tanya came to realise just how much they enjoyed teaching and education. Their PhD involved them creating a high school ecology unit that was focused on climate change and tick-borne diseases, when one of their colleagues forwarded them the call for a Project EDDIE postdoctoral researcher. "I read more about the project and its goals and quickly realised it paired well with my experience creating



DR. TANYA JOSEK

(Pronouns: they/them)

O'Reilly and Darnier Research Teams,
Illinois State University, USA

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FIELD OF RESEARCH

Entomology and Science Education

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RESEARCH PROJECT

Tanya is involved with Project EDDIE, which aims to empower students and give them a more realistic view of what it is to be a scientist.

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FUNDER

National Science Foundation

NSF IUSE 1821567 and IUSE 1821564

the Next Generation Science Standards ecology unit and my interest in moving towards having more of a science education focus,” says Tanya. “Importantly, the EDDIE community is open to everyone interested in teaching and/or producing modules, with faculty mentor networks to help provide community spaces.”

These spaces are a place where the community members can discuss how the teaching of modules is progressing and there are workshops that help bring individuals together to work on how best to develop modules.

IN WHAT WAYS DOES PROJECT EDDIE BENEFIT STUDENTS?

As well as the aforementioned experience in working with large datasets that the project provides, it also helps introduce students to a range of real-world experiences that will serve them well throughout their careers. The data used within the modules are real, which instantly lends the work an authenticity that cannot help but be beneficial. Of course, that real data are used means that a student’s analysis is valid and could actually make a difference to the field in which they are operating. Students are also given the opportunity to ask their own questions and

then use the data to answer those questions – a particularly important part of the scientific process.

Because the datasets are publicly available, there is no cost associated with obtaining them, which has its own benefits. As many students are coming together, they are able to compare their findings with each other; different types of analyses can help imbue each with greater meaning i.e., ‘do these alternative findings alter my own?’.

HOW CAN TEACHERS USE THE PROJECT’S OUTPUTS IN THE CLASSROOM?

Project EDDIE is composed of three initiatives: earth and ecosystems, macrosystems and environmental data. A huge range of teaching materials has been produced centred on the three areas, including ready-to-use modules that teachers can refer to in the classroom. Each module has instructor resources that are specific to that module and teachers are able to narrow each module down by subject and find ones that best fit their classroom objectives. In addition, there are other resources, such as statistical tests and software. There are even some statistical vignettes that were designed by Tanya’s colleagues, Dax

Soule and Michelle Weirathmueller. These vignettes include a diverse cast of characters to serve a wider use beyond the science. “Scientists in media are often depicted as cisgender, white men, which can make it hard for students who do not share that identity to see themselves in science. So, my role with the statistical vignettes was to focus on diversity and inclusion within the cast,” explains Tanya. “We also wanted to make sure that when designing and naming these characters that we didn’t white-wash them or unintentionally reinforce stereotypes. We based both the name and appearance of characters on real people and worked with cultural houses to come up with the initial designs.”

WHAT ARE THE NEXT STEPS FOR PROJECT EDDIE?

Tanya and the team are focusing on expanding the community and developing the modules. The amount of publicly available data is continuously growing, so the more the team can develop the modules, the more educators and students they can reach. It is Tanya’s ambition to complete their postdoctoral studies and then become a module developer.

USING PROJECT EDDIE IN YOUR CLASSROOM



READY-TO-USE MODULES

Project EDDIE provides a wealth of resources to enable you to support your students' learning. From ecological forecasting, to lake modelling, the modules cover a range of subjects related to the project sub-groups of: Earth and Ecosystems
Environmental Data
Macrosystems

The Project EDDIE team is very thorough and each module provides:

- Learning goals
- Context for use
- Teaching materials
- Teaching notes and tips
- Assessment
- References and resources

The aim is for teachers to be able to incorporate the modules into lesson planning as easily as possible. As an example, here is

an overview of the CLIMATE CHANGE MODULE.

LEARNING GOALS

- To analyse global temperature data to see if Earth's average global temperatures are really increasing
- To analyse CO₂ data to see if atmospheric levels are really increasing
- To correlate CO₂ data with global temperature to see if there is a relationship
- To compare current trends with rates of change during pre-historic periods using ice core data
- To interpret what these results mean for understanding current climate change
- To learn basic shortcuts and graphing in Excel

DESCRIPTION

In this module, students will explore how we know that the climate is changing, using both

recent records and pre-historic ice-core data, and will focus on graphing temporal data to examine these long-term changes.

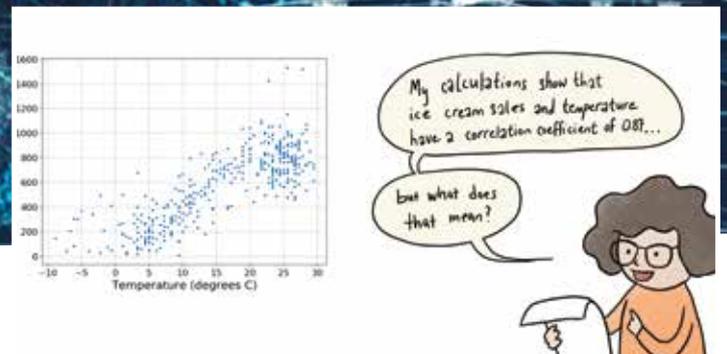
KEY QUESTIONS ASKED

- What controls the Earth's temperature?
- Is this global temperature changing over time? Is Earth 'warming'? If so, at what rate?
- What might be causing this change in global average temperature?
- How are temperature and CO₂ related?
- How can we compare the recent data to geologic history?

https://serc.carleton.edu/eddie/teaching_materials/modules/climate_change.html

TANYA'S TOP TIPS

- 01** Work towards creating an inclusive classroom. This requires a lot of work upfront, followed by continuous work to learn how our classrooms might be unintentionally promoting racist, ableist or homophobic material, references or even phrases. It's up to us to make our classrooms more inclusive.
- 02** It's okay to be wrong, not know something or for things not to work! It's important for your students to be reminded that you are only human – admitting you don't know something is a sign of strength not weakness. Work with your students to find the answer or find solutions to problems when labs don't work how you expected them to – this is an important part of the scientific process.
- 03** Rework, revisit and share. Our lessons are never perfect, so it's always important to go back and improve them. If you think your lesson is really good – share it so that other teachers have the chance to try it too! This can lead to further collaborations on future lessons.



STATISTICAL VIGNETTES

Designed to help teach quantitative concepts used in analysing data, Project EDDIE's statistical vignettes are based on a cast of diverse characters. The vignettes teach quantitative reasoning skills, while also representing the range of people in the STEM community. The aim is for students to gain the analytical skills needed to succeed in STEM, as well as an understanding that it is an area for them, regardless of their background or identity.

THE VIGNETTES COVER THE CONCEPTS OF:

- Correlation coefficient
- Significant figures
- Normal distribution
- Linear regression

Tanya has always been interested in the wider

role their scientific understanding can play; their academic aspirations do not focus on one particular dream project so much as a dream environment. "My dream is to create a classroom and research space that promotes the safety, wellness and joys of students and colleagues," says Tanya. "I want my work to help facilitate the creation of similar spaces within academia to benefit more and more people."

Working on the diverse characters for the statistical vignettes, Tanya is clearly playing their part in encouraging diversity and inclusion within STEM. Ensuring that LGBTQ+, BIPOC and people with disabilities are represented in the field is something Tanya is committed to and they believe that the two most important things are educating yourself and taking action. "It is important to find out how your field, academia and department have

been built to work against providing spaces for specific groups," explains Tanya. "It is essential that we all feel a responsibility to take real action, as opposed to performative action, to address and fix these issues."

Enabling better representation in the sciences is a challenge, but one that brings huge rewards. Tanya explains, "One of the things that I am most proud of is being able to be a co-author on a paper promoting LGBTQ+ inclusive practices in the biology classroom. All the authors on the paper were amazing to work with and I feel lucky to have been able to work with them and ultimately publish something that can help LGBTQ+ students."

Find out more about the diverse cast: <https://youtu.be/4rRdgf8CaFY>

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