futurum

INSPIRING THE NEXT GENERATION

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REDRESSING THE BALANCE

ALEISHA AMOHIA

Named one of 25 young New Zealand women changing the world, Aleisha is a passionate advocate for diversity and inclusion in the tech industry.

WELCOME

ISSUE 016
REDRESSING THE BALANCE

"There are real-world consequences for a tech industry lacking diversity," says Aleisha Amohia, named one of 25 young New Zealand women changing the world. Her vision for a more inclusive tech world is shared by many.

After the 2022 GCSE exam results, the UK Government issued a press release: "GCSE results show a surge in pupils taking valuable STEM subjects." Figures in this press release showed the number of secondary school students taking GCSEs in maths, computer science, science and engineering have risen, with overall entries for girls in STEM subjects up by more than 30,000 from 2014.

This month, the UK Government issued a further statement: "The Government's aim of increasing the share of GDP spent on R&D will require a workforce with suitable STEM skills as well as teachers able to train the next generation of researchers." Even with the increased uptake in secondary schools, it appears the UK Government is focusing its attention on STEM education.

Initiatives to close the STEM skills gaps and attract a more diverse and inclusive STEM workforce are proving successful, but more still needs to be done — in the UK and globally. Alongside Aleisha, we speak to Justine Sass, UNESCO Chief of the Section of Education for Inclusion and Gender Equality, and Marie Horton, Senior Research Analyst at EngineeringUK, about what we can do to make STEM a more attractive and inclusive career choice.

In striving for more diversity in STEM, however, we must not forsake SHAPE. Social sciences, humanities and the arts are as significant as science, technology, engineering and maths, with many researchers advocating the need for skills in both STEM and SHAPE. As Professor Ingela Naumann says, "I want to make a difference in the world. For me, researching and teaching social policy is a way to work towards a more equal society."

The interdisciplinary nature of today's world means we need more diversity and inclusion in all fields. With passionate advocates such as Aleisha and the many researchers featured in this issue, we know the balance is being redressed. And we need to keep going...

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ALEISHA AMOHIA

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“THERE ARE REAL-WORLD CONSEQUENCES FOR A TECH INDUSTRY LACKING DIVERSITY.”

IN 2020, **ALEISHA AMOHIA** WAS NAMED ONE OF 25 YOUNG NEW ZEALAND WOMEN CHANGING THE WORLD. SHE TELLS US WHY SHE IS A PASSIONATE ADVOCATE FOR DIVERSITY AND INCLUSION IN THE TECHNOLOGY INDUSTRY

WHO OR WHAT INSPIRED YOU TO STUDY COMPUTER SCIENCE AND AI?

I was one of the lucky ones who knew from a very young age that I wanted to work in technology, but there were a few key reasons that I ended up studying computer science.

Firstly, I grew up in a household that valued education, so I knew I wanted to go to university and widen my career options by getting a qualification, even though I was aware of other pathways into the tech industry.

Secondly, my favourite subject at school was Digital Technologies. I enjoyed my programming assignments and was proud of what I could create. I also had two awesome teachers who flew us from Wellington in New Zealand to Silicon Valley and Seattle in the US to show us what working in the tech industry could look like, and introduce us to other women who had made tech their careers.

Finally, I was able to get a taste of working in the tech industry, specifically in an open source project team, before I started studying. This experience taught me that I definitely wanted to do more in the tech industry, but that I still had plenty of learning and growing to do.

I chose computer science and AI because I wanted to be prepared, and gain all the tools I needed to do the work I wanted to do – but I also thought it sounded cool!

WHY DID YOU STUDY MANAGEMENT AND INFORMATION SYSTEMS ALONGSIDE COMPUTER SCIENCE AND AI?

Growing up, I was super aware of the stereotypes surrounding people who worked in technology – socially awkward, bad at communicating, and often carrying negative attitudes toward people or concepts they disagree with or don’t understand.

I also found myself feeling that sometimes the tech industry gets caught up in making things as cool, fast or impressive as possible, and I don’t necessarily agree that this is the best way to ensure we’re building things to genuinely improve people’s lives.

Therefore, I chose to study commerce alongside computing, so that I could also study people. I wanted to learn how to communicate with those who disagreed with me, and with the people who made the big decisions about how technology is used and developed.

> “
> **TOO MANY WOMEN LEAVE ENGINEERING AND COMPUTER SCIENCE COURSES,** SO I WANTED TO GIVE MY ENERGY TO CREATING A SPACE THAT MADE PEOPLE LIKE US FEEL SAFE AND VALIDATED.
> ”

Left to right: Hon. Marama Davidson with Jahla Tran-Lawrence, Maddi Rowe and Aleisha Amohia (Wellington Alliance Against Sexual Violence), attending the launch of Te Aorerekura: National Strategy to Eliminate Family Violence and Sexual Violence

WHY DO YOU LOVE STUDYING AND WORKING IN TECH?

Studying and working in tech has allowed me to draw on all the different parts of myself – I can be creative and logical, work on my own and with others, write code and write articles, get lost in a solo project and speak publicly at events, teach others and continue to learn. I love to challenge myself, build and fix things, and know that the work I'm doing is going to make someone's job or life easier.

I also work in open source software, which is even more special because it is 'by the people, for the people'. I work on an open source library system called Koha which is used by over 18,000 libraries worldwide and completely community-driven. Nothing goes into the software without others in the community testing and approving it, and we get feedback directly from people who will actually use Koha (library users and staff). This is an example of how technology is only as strong as the community contributing to it. Koha is a powerful, global project because it is a product of the people, of which I am very proud to be part.

HOW DID YOU BECOME PRESIDENT OF VICTORIA UNIVERSITY OF WELLINGTON WOMEN IN TECH?

Victoria University of Wellington Women in Tech (VUWWIT) was originally a group of engineering students who organised casual meet-ups. I joined the committee in my second year and since most of the original members were graduating at the end of the year, I realised I had to take action to make sure VUWWIT didn't leave with them. That action involved formally registering VUWWIT as a club with the university (which made us eligible for free venue hire on campus and funding applications), putting together a constitution, and getting members signed up. I was the first official President of VUWWIT for two years until I finished university.

WHAT DID YOU GAIN FROM YOUR EXPERIENCE AS VUWWIT PRESIDENT?

Being involved with VUWWIT was significant. As a Māori-Asian woman studying male-dominated subjects, the overwhelming culture of toxic masculinity and lack of support for women (which is common in the tech industry and certainly not unique to the university) left me feeling isolated, stressed and incapable. I knew I couldn't be the only person feeling this way, so I ventured out to find a community of people who advocated for (or needed) a more diverse, inclusive tech industry, just like me. Too many women leave engineering and computer science courses, so I wanted to give my energy to creating a space that made people like us feel safe and validated.

IS THIS WHY YOU ARE A PASSIONATE ADVOCATE FOR DIVERSITY AND INCLUSION?

The tech industry has been my focus because, naturally, I want the spaces that my colleagues and I exist in to be welcoming and safe for us. Most of the people who work close to me are young, or Māori, or women, or disabled, or a combination of identities, and the tech industry is not always designed to support or enable us to be our best.

There are also real-world consequences for a tech industry lacking diversity. The products and services around us are all powered by tech or have technological aspects – tech touches everything. It can cause problems and possibly become dangerous if engineers and developers neglect to consider and include the needs and experiences of all potential users into their tech solutions.

HOW DID YOU BECOME INVOLVED WITH THE MĀORI DESIGN GROUP AT INTERNETNZ?

A few friends recommended me for the position, and I agreed because it is an opportunity to work with an organisation that is willing to invest in implementing some real structural and cultural change to honour Te Tiriti o Waitangi [the Treaty of Waitangi] in their work. I'm also beyond excited to be working with an inspirational team who are experts in their respective fields, and I have already learned a great deal from them.

DO YOU FEEL THAT YOU ARE FULFILLING YOUR DREAMS AS A SOFTWARE DEVELOPER AT CATALYST IT?

Catalyst IT has been awesome. They employed me after I was a student in the Catalyst Open Source Academy in 2014 – first as an intern, then in a permanent part-time role while I was at university, and now full-time since graduating. I'm pleased to say this is exactly what I wanted to do after graduating. Catalyst allows me to explore all my interests, from programming to politics, and supported me with a scholarship while I studied, which went above and beyond what I had imagined.

Members of the 2020 Organising Committee of the Wellington Branch of National Council of Women New Zealand: Ashlee Metcalfe, Aleisha Amohia, Rabeea Inayatullah, Sonja Randhawa, Harita Gandhi and Prudence Stone © Colin McDiarmid

> "I LIKE TO THINK **I'M CONTRIBUTING TO A MOVEMENT** THAT STARTED LONG BEFORE ME, AND I HOPE THAT I'VE HELPED A FEW YOUNG WOMEN WITH THEIR OWN JOURNEYS INTO TECH AND OTHER MALE-DOMINATED AREAS."

Aleisha at her graduation from Victoria University of Wellington in 2020

WHAT DO YOU IMAGINE FOR YOURSELF IN THE FUTURE?

I'd love to find an intersect between my political and technological interests. Catalyst has allowed me to have a flexible schedule and make time for all of my commitments, which shows how much they value diversity and inclusion initiatives. In an ideal world, in the future, we'd all be able to simply do the work we enjoy without also needing to advocate for ourselves and other people from marginalised groups. Until we achieve that, I imagine myself still working on tech solutions that continue to centre people.

WHAT CHALLENGES HAVE YOU HAD TO OVERCOME TO GET TO WHERE YOU ARE TODAY?

Most of the challenges I've faced have been a result of working in a male-dominated industry and in a colonised country. I find myself being questioned and challenged on things that are not only blatantly obvious to me but have also been thoroughly confirmed by research and evidence.

For example, I'm always asked to explain why we need groups like VUWWIT and whether gender inequity is still a problem. I'm told that women are simply not choosing careers in tech and that's why we are in the minority. I'm invited to promotional photoshoots because my identity is marketable. I'm told that Te Reo Māori is a dying language and that I'm always going to be fine in my career because companies will hire me to fill their diversity quotas.

HOW DO YOU OVERCOME THESE CHALLENGES?

I have learned to overcome this ignorance (usually accompanied by tokenism, racism, ableism and misogyny) by choosing my battles. I've learned to establish who has a genuine interest to learn and engage, and who is searching for an opportunity to assert their own opinions. As much as possible, I'll direct people to articles or resources where they can get information in their own time, from people who have already done the work. That way, I can preserve my energy for the initiatives that I've actually signed up for, rather than spending it on emotional and unpaid labour.

HOW DID IT FEEL TO BE NAMED ONE OF 25 YOUNG NEW ZEALAND WOMEN CHANGING THE WORLD?

It was an absolute honour to be included in the Y25 2020 list, alongside a group of women who are doing incredible things and are a massive inspiration for me. I feel like, together, we are changing the balance. There are more people willing to have uncomfortable conversations that will change the world – and they have to be uncomfortable otherwise there will never be change. There's still plenty of work to do but there's more of us doing it now.

DO YOU FEEL LIKE YOU ARE CHANGING THE WORLD?

I like to think I'm contributing to a movement that started long before me, and I hope that I've helped a few young women with their own journeys into tech and other male-dominated areas.

IF THERE IS ONE THING YOUNG PEOPLE SHOULD KEEP IN MIND, WHAT DO YOU THINK THAT SHOULD BE?

Don't be afraid to challenge the system, and surround yourself with people who remind you of who you are.

ABOUT ALEISHA

Aleisha has always had a strong interest in technology. At school, she was the technology prefect, ran the school technology club, and completed the Catalyst Open Source Academy when she was 15 years old.

Aleisha graduated from Victoria University Wellington in New Zealand with a BSc in Computer Science & Artificial Intelligence and a BCom in Management & Information Systems. She is currently Koha Development Lead at Catalyst IT, Co-Chair of Māori Design Group at InternetNZ, YWCA Greater Wellington Board Member, Wellington Alliance Against Sexual Violence Board Member, and Co-President of the National Council of Women of New Zealand (Wellington).

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WHY GOOD CHILDCARE PROVISION IS IMPORTANT FOR GENDER EQUALITY

THE UK HAS SOME OF THE HIGHEST CHILDCARE COSTS IN THE WORLD. FOR MANY FAMILIES, THIS MEANS IT IS MORE ECONOMICAL FOR ONE PARENT TO GIVE UP WORK THAN IT IS TO PAY FOR FULL-TIME CHILDCARE. USUALLY, THIS WILL BE THE MOTHER. **INGELA NAUMANN** IS PROFESSOR OF COMPARATIVE SOCIAL POLICY AT THE **UNIVERSITY OF EDINBURGH** IN THE UK. BY INVESTIGATING THE GENDER INEQUALITIES CAUSED BY INSUFFICIENT CHILDCARE PROVISION, SHE HOPES TO INFLUENCE POLICY CHANGES SO THAT WOMEN CAN BE MOTHERS AND HAVE SUCCESSFUL CAREERS AT THE SAME TIME

TALK LIKE A SOCIAL POLICY RESEARCHER

MATERNITY LEAVE – the time a mother takes off work after the birth of a child. In the UK, a mother is entitled to 52 weeks of maternity leave, 39 of which are paid

PATERNITY LEAVE – the time a mother's partner takes off work after the birth of a child. In the UK, a mother's partner is entitled to 2 weeks of paid paternity leave

SHARED PARENTAL LEAVE – the combined time both parents take off work after the birth of a child. In the UK, both parents can share 50 weeks of leave and 37 weeks of pay

GENDER NORMS – societal ideas about how different genders should behave

QUALITATIVE DATA – data describing qualities or characteristics of something

QUANTITATIVE DATA – data expressing quantities and numerical values

WHY RESEARCHING GENDER EQUALITY IS IMPORTANT

When she was seven years old, Professor Ingela Naumann's daughter came to her, distraught. "Mum, I don't know what to do," she said. "I really want to be a herpetologist when I grow up, but I also want to be a mum. I don't know which one to choose."

This encounter had a strong impact on Ingela, a professor of comparative social policy at the University of Edinburgh. She is interested in how government policies promote or hinder gender equality in society. "We are allegedly promoting gender equality and equal opportunities for women, and, yet, by the time they are seven, girls are already aware that society is not as equal as we like to believe," she says. "Society makes it difficult for girls to combine their dreams of flying high with being mothers."

Ingela's daughter's comment is particularly striking, given her family background. With a working mother, grandmother and great-grandmother, she had grown up surrounded by role models of women who had successful and fulfilling careers alongside raising a family. The idea that she could not be a scientist and, also, a mother had not come from within her family, so why did she think she could not be both? Despite her family background, society's expectations have a strong influence on Ingela's daughter. Growing up in 21st century Scotland, she is exposed to cultural and societal norms that teach her that women must make a choice: to have a career or to be a mother. Ingela is determined to influence policy and society so that girls no longer believe this.

Ingela with her daughter, who now wants to be an eco-engineer when she grows up

PROFESSOR INGELA NAUMANN

School of Social and Political Science, University of Edinburgh, UK

FIELD OF RESEARCH

Social Policy

RESEARCH PROJECT

Investigating the importance of childcare services for gender equality and examining family well-being during COVID-19

FUNDER

Economic and Social Research Council (ESRC)

Ingela enjoys exploring the outdoors

WHY GOOD CHILDCARE PROVISION IS IMPORTANT FOR GENDER EQUALITY

In the UK, gender norms and insufficient childcare provision are key barriers to gender equality in the workplace. "It is all very well to say that women and men have equal rights in the labour market," says Ingela, "but what should parents do with their babies while they work?"

Traditional gender roles are still ingrained in UK society when it comes to the responsibility of raising a family. A mother is much more likely to give up work to care for children than a father is. Indeed, it was only in 2015 that the law changed to allow both parents (including same-sex parents) to share parental leave after a baby is born. Prior to that, only mothers were entitled to 52 weeks of maternity leave after giving birth, while their partner had to return to work after only two weeks of paternity leave. Once parents return to work, they must come up with their own childcare solution, either by finding a childcare place with a nursery or childminder, or by involving grandparents, wider family and friends.

This situation is not the same everywhere. Nordic countries, in particular, offer extensive support for parents to combine work and care responsibilities. In Sweden, for example, shared parental leave has been a reality since the 1970s. It is 18 months long and includes generous income replacements for most of this time. In addition, all children over the age of one are entitled to full-day, year-round childcare if their parents are working. While this childcare is not free, it is heavily subsidised so is affordable to parents, allowing more than 85% of Swedish mothers to work, with 71% pursuing full-time employment. Fathers claim a third of all paid parental leave in Sweden, as they are also expected to take time off to care for their children.

This Swedish advertising campaign from the 1970s, featuring weightlifter Hoa-Hoa Dahlgren, encouraged more fathers to take parental leave © Reio Rüster, Försäkringskassan (Swedish Social Insurance Agency)

In England, all children are entitled to 15 hours of free early education per week during term-time, from the time they turn three until they start school. This entitlement is extended to 30 hours per week for children of working parents. In Scotland, all three- and four-year-olds are entitled to 30 hours of free nursery education, whether their parents are working or not. While this is one of the most generous provisions of early childhood education in the world, it does not solve the problem of what happens to a child between the age of one, when parental leave ends, and the age of three, when free nursery begins. Nor does the free nursery entitlement support parents who work full-time, as the timing (usually 9am to 3pm) is incompatible with the hours of most jobs, and school holidays are not

Ingela and her family enjoy adventure activities such as this chain walk

covered. So, who will care for the children when their parents are working?

THE COST OF CHILDCARE

With little public childcare available in the UK for children aged one to three, and additional childcare needed in the mornings, afternoons and holidays for children aged three and up, parents are forced to pay for private childcare. This can cost over £1,000 per month. "The UK has some of the highest childcare costs in the world![1]" says Ingela. "For many families, it is impossible to balance the high cost of childcare with their income." It is often more economical for one parent to reduce their working hours, or give up work completely, than it is to pay for full-time childcare. "Unfortunately, this is usually the mother."

The gaps in current childcare policy mean that families often slip into traditional gender roles, where women care for the children and men focus on providing for the family. This perpetuates gender inequalities - it creates barriers for mothers to have a successful working life and financial independence, and it creates barriers for fathers to be fully involved in caring for their children.

Ingela works closely with policymakers in the Scottish Government as she investigates the gender inequalities that result from a lack of affordable childcare services. In her research, she examines and compares social policies across different countries to better understand which policies best support equal parenting and gender equality in the labour market. She uses this method of evidence-based policy learning to advise the government on how policies should be changed to create better conditions for gender equality in the UK.

HOW DID COVID-19 IMPACT FAMILY WELL-BEING?

In March 2020, as COVID-19 hit the UK, a national lockdown was enforced. Schools and childcare facilities were closed, leaving parents to juggle the responsibilities of home-schooling, childcare, domestic chores and work, all while isolated within their family bubble. "The situation provided us with a bleak real-life experiment to explore the question 'What happens if childcare infrastructure is removed?'" explains Ingela. She collaborated with various non-academic partners, including the Scottish Government, One Parent Family Scotland and Child Poverty Action Group, to investigate the impacts of lockdown on family well-being.

> **"We have a strong message coming out from this research. Women have borne the brunt of this pandemic."**

Ingela and her research team conducted qualitative interviews with families throughout Scotland, covering a range of different family situations. These included single-parent families, families containing keyworkers, dual-earner families, families with underlying health conditions and families from both urban and rural areas.

The interviews gave detailed insights into the experiences of families and the challenges they faced during the pandemic. The team also analysed quantitative data from large-scale UK surveys to understand general health and well-being trends in families during the pandemic. This research generated rich evidence on the way the pandemic affected children and their parents. "On a positive note, we found that families were amazingly resilient," says Ingela. "Parents worked incredibly hard to protect their families, to keep life going." However, this came at a cost. Ingela's research revealed that the mental and emotional well-being of both children and parents suffered during lockdowns.

"We have robust evidence showing that mothers were particularly impacted by the mental strain of lockdown, and especially mothers with two or more children," says Ingela. The research shows that looking after the family, including home-schooling, domestic chores and caring for children, was predominantly done by women. At the same time, many of these mothers were also trying to work from home. Ingela's results show this had a strong impact on women's mental health. "We have a strong message coming out from this research," she says. "Women have borne the brunt of this pandemic."

CHANGING POLICY AND SOCIETY

The Scottish Government has pledged to expand childcare provision before and after the school day and during holidays and has invited Ingela to share her expertise and advice on the development of its new childcare policy. Ingela's research into childcare and family well-being will contribute to national policy changes that hopefully lead to societal shifts in gender norms. "It is important to point out that this isn't an issue for women to solve, but for society as a whole," explains Ingela. We need a society where fathers can be fully involved in the care of their children. And we need the next generation of young women to grow up knowing they can have a successful career while also being a mother, and that they can truly be whatever they want to be.

[1] *OECD Data (**data.oecd.org/benwage/net-childcare-costs.htm**)*

HOW DID INGELA BECOME A SOCIAL POLICY RESEARCHER?

I study social policy because I want to make a difference in the world. From a young age, I was politically active and wanted to change the world to make it a more equal place. My journey led me to become a social policy researcher, as this enables me to make an impact on society by sharing my knowledge with students, policymakers and the public.

I grew up in Switzerland with a Swedish mother and a German father. My Swedish heritage strongly shaped my identity as a girl and young woman. I grew up as the third generation of working women (my grandmother was a midwife who skied across Northern Sweden to deliver babies), so I knew that when I was older, I would work, whether I had children or not. This is the cultural norm for women in Sweden, so it was in my DNA.

But Swiss culture in the 80s and 90s contrasted with the values I had learnt from my mother and grandmother. Beyond my family, I was surrounded by a more 'traditional' society, where girls were expected to grow up, marry, have children and stop working.

So, in my teens, I started to engage with feminist politics. My international background made me aware of the cultural differences between countries when it comes to gender norms and triggered my interest in studying different societies. I left Switzerland and began my academic journey, studying social and political science, history and gender studies around the world, in Berlin, New York, Amsterdam, Florence...

I chose Comparative Social Policy as my research field because it allows me to better understand not only why different countries have different attitudes to gender, work and childcare, but also what concrete policy solutions can improve gender equality.

When I became a social policy lecturer at the University of Edinburgh, I experienced first-hand, as a mother of two young children, how difficult it was to combine a career with care responsibilities in the UK. I began to use my expertise in international social policy to engage with the government and other stakeholders to influence policy changes towards better childcare provision.

For me, researching and teaching social policy is a way to work towards a more equal society. I want to influence childcare policy changes at a national level, so that women no longer feel they must choose between a career or having children, and so that men can be fully involved in caring for their children.

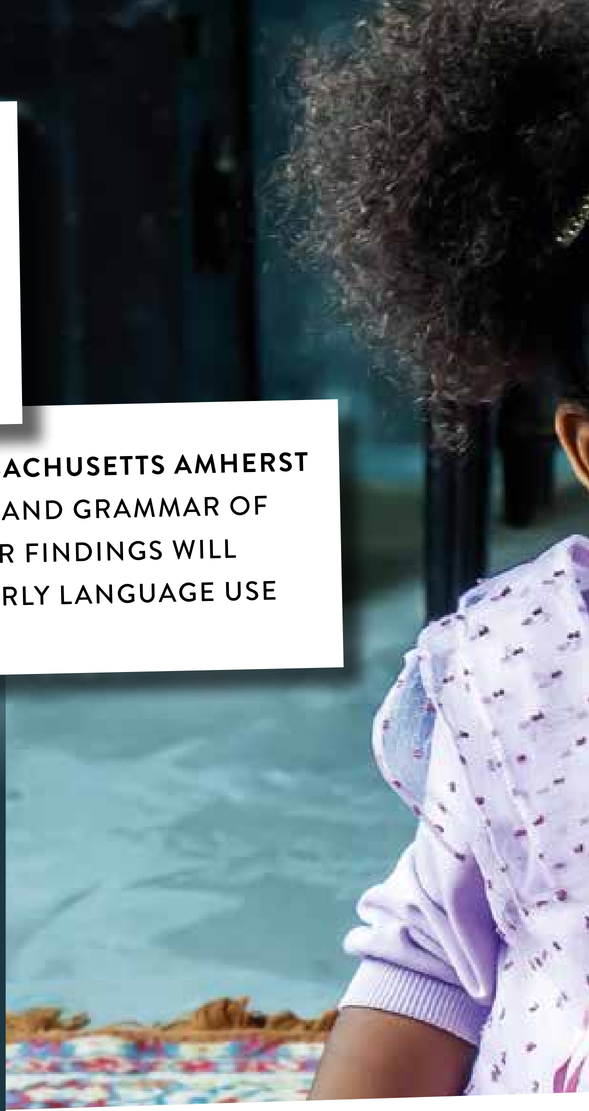
My vision is for a world where all children, regardless of gender, can follow their dreams and reach for the sky.

"I want to influence childcare policy changes at a national level, so that women no longer feel they must choose between a career or having children, and so that men can be fully involved in caring for their children."

"My vision is for a world where all children, regardless of gender, can follow their dreams and reach for the sky."

VARIATION AND GRAMMAR IN AFRICAN AMERICAN ENGLISH

PROFESSOR LISA GREEN, BASED AT THE **UNIVERSITY OF MASSACHUSETTS AMHERST** IN THE US, LEADS RESEARCH INVESTIGATING THE VARIATION AND GRAMMAR OF AFRICAN AMERICAN ENGLISH IN CHILDREN AND ADULTS. HER FINDINGS WILL INCLUDE INSIGHTS INTO THE PROPERTIES OF CHILDREN'S EARLY LANGUAGE USE AND THE STAGES OF DEVELOPMENT INVOLVED



TALK LIKE A LINGUIST

AFRICAN AMERICAN ENGLISH (AAE), ALSO KNOWN AS AFRICAN AMERICAN LANGUAGE – a linguistic variety which may be used by speakers who have contact or close association with networks of communities of African Americans

DIALECT – a particular form of a language which is peculiar to a specific region or social group

GRAMMAR – the branch of linguistics looking at syntax and word forms

LANGUAGE ACQUISITION – the process by which humans acquire the capacity to perceive and comprehend language

LANGUAGE DISORDER – a significant impairment in the acquisition and use of language

LEXICAL PATTERN – words that occur in language with high frequency

PERFECT TENSE – a verb form (used with a form of 'to have') to show something has been or will be completed. For example, I have walked, I had walked and I will have walked

PHONETICS – the study of classification of speech sounds

PHONOLOGY – the study of speech sounds of a language or languages

PROSODY – the rhythm, stress and intonation of speech

SEMANTICS – the branch of linguistics and logic concerned with meaning

SYNTAX – the study of how words combine to form larger units such as phrases and sentences

TENSE – the form of a verb used to indicate time of action (in terms of *when* it is uttered, for example, past, present, in the future or continuing)

For most of us, acquiring language seems to have happened automatically – so easily, in fact, that it is hard for us to comprehend a time when we did not speak and communicate as we do now. Of course, along the path of learning language, many of us will have faced challenges – be it how to pronounce words, finding the confidence to put words together into a coherent sentence or even learning a completely new language – but it can seem as if our linguistic abilities have always been with us.

For researchers in the field of linguistics, the ways in which we acquire properties of language, including dialects of languages, and how we use them, is of huge interest – it is a complex field that poses more questions than our supposedly innate ability to acquire language might first suggest. Consider the English language, for example. In 2021, there were approximately 1.4 billion English speakers in the world, and the range of those speakers meant that there were many variations of the English language around the globe. How do these forms of English vary? How do speakers of these variations acquire their language? What are the implications of this for education and other social contexts? In what ways are different forms of English perceived?

Professor Lisa Green is a researcher at the University of Massachusetts Amherst who is exploring the intricacies of language. Currently, she is involved with research projects on variation and grammatical patterns in child and adult African American English (AAE).

WHAT RESEARCH METHODS ARE USED WHEN EXAMINING DIALECT ACQUISITION?

In conducting the child AAE research, Lisa interacts with children (aged three to six years old) who describe toys and objects as they explore and play with them in different make-believe contexts, which enables her to collect examples of spontaneous speech. She also collects data in experimental settings, where she uses structured prompts to elicit children's responses. Lisa then uses linguistic description and general principles of linguistic theory to analyse the data. In addition, quantitative analysis of certain constructions and verb endings, such as -ed or -s, can be useful in understanding how children use certain forms of language along their developmental paths.

WHAT COLLABORATIONS HAS THE RESEARCH BENEFITED FROM?

Some of the projects associated with this research are collaborative efforts with Brandi Newkirk-Turner, who is the Professor of

PROFESSOR LISA GREEN

Department of Linguistics, University of Massachusetts Amherst, USA

FIELD OF RESEARCH

Linguistics

RESEARCH

Investigating the variation and grammar of African American English

FUNDER

US National Science Foundation (NSF)

EAGER: Collaborative Research: Variation and the Grammar of Child African American English
Grant #1744503
(co-PI: Professor Brandi Newkirk-Turner)

Understanding Variation in African American Language: Corpus and Prosodic Fieldwork Perspectives
Grant #2042939
(co-PIs: Kristine Yu, Lisa Green, Brendan O'Connor, Meghan Armstong-Abrami)

Communicative Disorders and Associate Provost of Academic Affairs at Jackson State University in the US. This collaboration on the EAGER project brought together data from the states of Mississippi and Louisiana. "Given Dr Newkirk-Turner's expertise in the field of communicative disorders, through this research, we have been able to address questions raised in both fields – linguistics and communicative disorders," explains Lisa. "In addition, in bringing the two areas together, we have been able to make some advances in discussions about how our research can be extended to practical applications. For instance, in one publication, we explained how speech pathologists could extend what we found in our research to assessment."

WHAT QUESTIONS IS LISA ATTEMPTING TO ANSWER?

As a linguist, Lisa is concerned with typical language development, so some of the questions that her research is attempting to answer are: 'What does typical development of variation in AAE-speaking communities look like?', 'What is the overlap between typical development of variation and variation in AAE?' and 'What are these degrees of variation?'

In her collaborative project concerned with sentence structure, meaning and prosody, Lisa, along with UMASS Amherst colleagues in linguistics, computer science, and Spanish and Portuguese, is aiming to develop linguistic analytical tools to better understand prosody in AAL. Despite a lack of research, claims have been made that ethnic identification of African Americans is possible based on small amounts of speech. In addition, there have been several claims about 'sounding Black' and features of AAE prosody. "Some general properties, such as wider pitch range, have been identified in AAE. However, very little prosodic research has been conducted on the linguistic variety," says Lisa. "In addition to determining patterns of intonation in AAE, further research could provide information about the extent to which current conventions for annotating contours in general American English can be used for AAE."

WHAT HAS THE PROSODIC FIELDWORK LOOKED LIKE IN PRACTICE?

Lisa began conducting research in a small community in southwest Louisiana more than 25 years ago and has continued to work with speakers of all ages in that community ever since. One of the areas of focus for this fieldwork has been BIN, a remote past marker in AAE. "BIN has been described as a stressed element, so elicitation tasks were used – tasks that were designed to elicit the past participle 'been', which is used in perfect tense contexts and to elicit BIN in different contexts," explains Lisa. "Participants listened to recorded scenarios and responded with a sentence that contained either BIN or been. Although the spelling of the target form was always b-e-e-n in the tasks, participants pronounced the form with the remote past pronunciation (BIN), in which case the marker bears prominence, or with the 'regular' participle pronunciation, depending on their interpretation of the meaning conveyed by the scenario."

WHAT IS THE REAL-WORLD IMPACT OF THIS RESEARCH?

Given that intonation in AAE, in general, and prosodic marking of BIN, in particular, are widely discussed but significantly understudied, Lisa's research will contribute linguistic descriptions of parts of AAE prosody in current frameworks, which can be used in comparative studies of varieties of American English.

Importantly, this research will have practical application in areas such as education and the justice system, where questions about ethnic identification, discrimination and social justice in relation to 'sounding' a certain way are relevant.

WHAT ARE THE NEXT STEPS?

Lisa intends to continue her work on developmental AAE among children, and she also intends to work on the structure of AAE and continue to collaborate with researchers at the University of Massachusetts Amherst in investigating variation in AAE in different regions of the US. "I want to analyse regional variation in AAE and explore the concept of AAE on a continuum in which speakers of different backgrounds and members of different types of social networks produce AAE in varying degrees," says Lisa. "Then, there is my book project, which explores research on AAE over the past 50 years."

ABOUT LINGUISTICS

Linguistics is the scientific study of language and involves analysing various aspects, such as form, structure and context. As with Lisa's research, linguistics can also investigate the relationship between sound, sentence structure and meaning, and how language varies between people, demographics and situations.

WHAT MOTIVATES LISA TO WORK IN THIS FIELD?

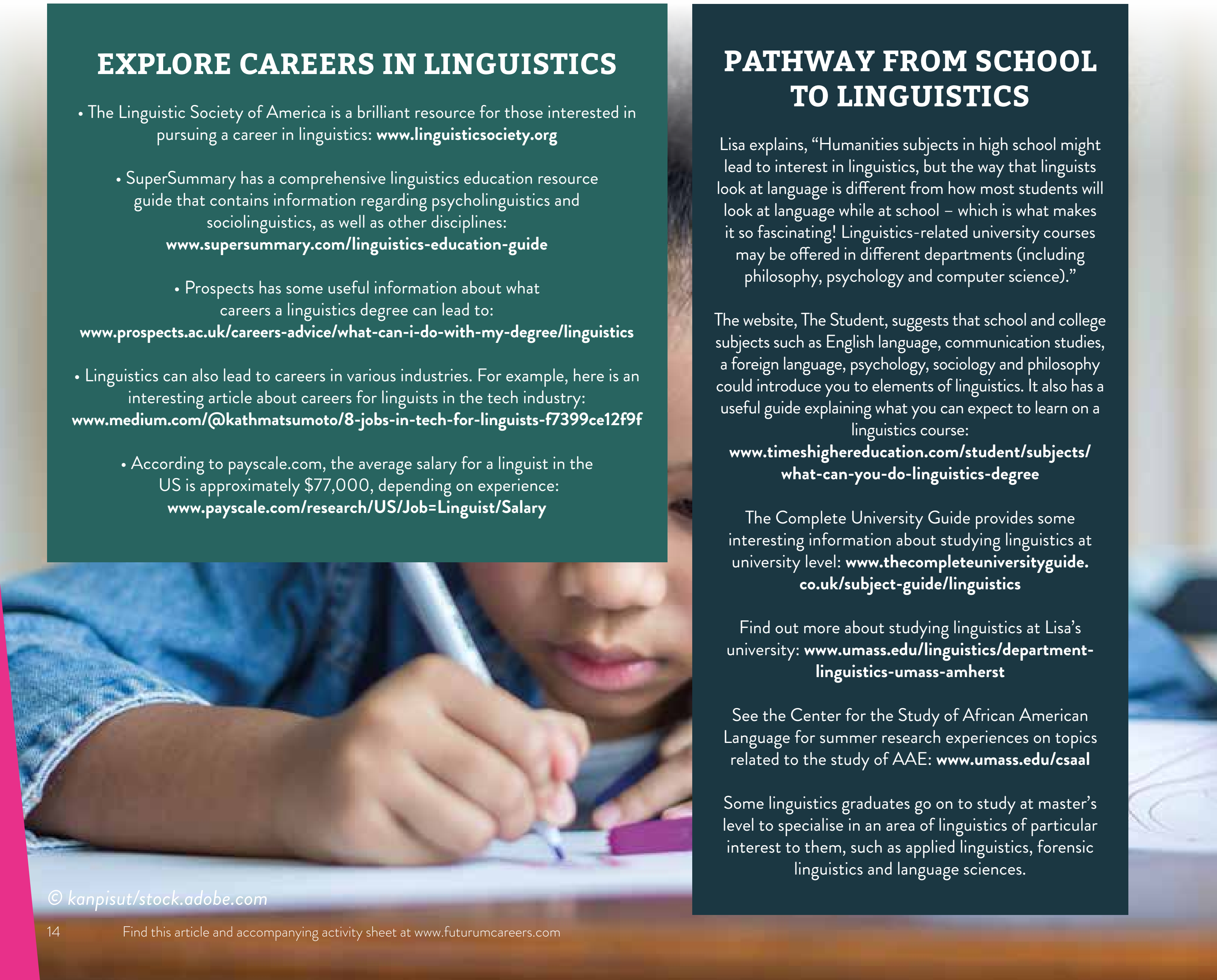
Lisa's research helps her to learn more about the structure of African American English. "Over the years, less attention has been paid to AAE as a linguistic system that is used in social contexts and as a marker of identity," explains Lisa. "I am motivated by the many unanswered questions about different components of the grammar of AAE. Also, results from this research have potential for practical application in areas such as education, speech pathology and social realms."

WHAT CAREERS ADVICE CAN LISA OFFER?

In considering linguistics, it is important for students to understand whether they are more interested in the type of training one receives in linguistics programmes that would strengthen their transferable skills or whether they are focused on linguistics because they want specific careers in the field (e.g., computational linguistics, linguistics in higher education or academia). "If you are interested in the training you would receive in undergraduate programmes in linguistics, you should understand what types of skills you would acquire and what types of occupations those skills would match," says Lisa. "If you want a career in fields in linguistics, you should be prepared for graduate training, especially for academia-related careers."

IN WHICH AREAS WILL THE NEXT GENERATION OF LINGUISTS FOCUS THEIR RESEARCH ATTENTIONS?

Some future linguists will focus on computational linguistics, a growing field which continues to expand in directions such as computational sociolinguistics, especially given the focus of social media and large corporations. There is already considerable interest in the use of AAE on social media and its influence, so it is likely that research on AAE will be conducted in different areas of computational linguistics.



EXPLORE CAREERS IN LINGUISTICS

- The Linguistic Society of America is a brilliant resource for those interested in pursuing a career in linguistics: **www.linguisticsociety.org**
- SuperSummary has a comprehensive linguistics education resource guide that contains information regarding psycholinguistics and sociolinguistics, as well as other disciplines: **www.supersummary.com/linguistics-education-guide**
- Prospects has some useful information about what careers a linguistics degree can lead to: **www.prospects.ac.uk/careers-advice/what-can-i-do-with-my-degree/linguistics**
- Linguistics can also lead to careers in various industries. For example, here is an interesting article about careers for linguists in the tech industry: **www.medium.com/@kathmatsumoto/8-jobs-in-tech-for-linguists-f7399ce12f9f**
- According to payscale.com, the average salary for a linguist in the US is approximately $77,000, depending on experience: **www.payscale.com/research/US/Job=Linguist/Salary**

PATHWAY FROM SCHOOL TO LINGUISTICS

Lisa explains, "Humanities subjects in high school might lead to interest in linguistics, but the way that linguists look at language is different from how most students will look at language while at school – which is what makes it so fascinating! Linguistics-related university courses may be offered in different departments (including philosophy, psychology and computer science)."

The website, The Student, suggests that school and college subjects such as English language, communication studies, a foreign language, psychology, sociology and philosophy could introduce you to elements of linguistics. It also has a useful guide explaining what you can expect to learn on a linguistics course: **www.timeshighereducation.com/student/subjects/what-can-you-do-linguistics-degree**

The Complete University Guide provides some interesting information about studying linguistics at university level: **www.thecompleteuniversityguide.co.uk/subject-guide/linguistics**

Find out more about studying linguistics at Lisa's university: **www.umass.edu/linguistics/department-linguistics-umass-amherst**

See the Center for the Study of African American Language for summer research experiences on topics related to the study of AAE: **www.umass.edu/csaal**

Some linguistics graduates go on to study at master's level to specialise in an area of linguistics of particular interest to them, such as applied linguistics, forensic linguistics and language sciences.

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HOW DID LISA BECOME A LINGUIST?

WHAT WERE YOUR INTERESTS WHEN YOU WERE GROWING UP?

I was always interested in reading books and writing, and putting the two together. I started writing a book when I was in 8th grade. I was also interested in areas of nursing and psychiatry based on what I had seen on television.

WHO OR WHAT INSPIRED YOU TO BECOME A LINGUIST?

My interest in linguistics was sparked by a visiting professor at my undergraduate institution and by a professor in my MA programme. My fascination with language in the works of Zora Neale Hurston led me to raise questions about how the study of dialects related to research in linguistics.

WHAT DO YOU ENJOY ABOUT LINGUISTIC RESEARCH AND TEACHING?

There are two reasons I am passionate about research in linguistics. First, it gives me insight into how languages vary, especially non-standard dialects, which are not always discussed in general linguistics. Also, some of the angles of my research have the potential to impact more practical areas such as education and speech pathology. Teaching gives me the opportunity to share information with students who have little or no interaction with understudied language communities, and it forces me to think about my research and find effective ways to convey it to students.

WHAT ARE YOUR PROUDEST MOMENTS, SO FAR?

In fall 2021, I taught an upper division undergraduate course on language in social contexts. Some of the cutting-edge research on these topics is being conducted by linguists whom I either taught or worked with on their dissertation research. I invited a few of these linguists to talk to my class about their projects; it was a great experience to see how much these young researchers have achieved and what excellent contributions they are making.

WHAT ARE YOUR AMBITIONS FOR THE FUTURE?

My goal is to continue to contribute to research on AAE and, as Director of the Center for the Study of African American Language, to continue to work on projects that foster and integrate basic research on language in the African American communities and applications of that research in educational, social and cultural realms. Some of these projects involve summer programmes, during which college students from Historically Black Colleges and Universities (HBCUs), as well as predominantly white institutions in the US, gain research experiences as they learn about the structure of AAE through working on data. Some of the participants have enrolled in graduate programmes in linguistics and linguistics-related disciplines and gone on to become published college professors.

LISA'S TOP TIP

People should have a clear understanding of what linguistics is, the career opportunities that might be available and the type of preparation necessary for those careers. Take the opportunity to read about linguistics and the types of projects linguists develop.

IT'S A CLITIC: HOW WE PROCESS LANGUAGE STRUCTURES

EVEN IF WE DO NOT OFTEN THINK ABOUT IT, WE ALL KNOW HOW TO CONSTRUCT SENTENCES IN OUR NATIVE LANGUAGE, AND THESE STRUCTURES MAY AFFECT HOW OUR MINDS PROCESS INFORMATION. **PROFESSOR ALICE HARRIS** IS SEEKING TO UNDERSTAND HOW PEOPLE WHO SPEAK DIFFERENT LANGUAGES PROCESS AN IMPORTANT BUT OFTEN-OVERLOOKED LINGUISTIC FEATURE CALLED A CLITIC

TALK LIKE A LINGUIST

AFFIX — an addition to a word that modifies its meaning

CAUCASUS — a mountainous region between the Black and Caspian Seas that includes the nations of Armenia, Azerbaijan, Georgia and parts of southwest Russia. The region is known for its linguistic diversity

CLITIC — small word that is pronounced with another word

HOST — in linguistics, the base word to which a clitic attaches

LANGUAGE — a structured form of communication used by humans

LINGUISTICS — the scientific study of language and its structure

Linguists write the word or phrase they are discussing in italics, such as *You'll read this.* If the word or phrase is in a foreign language, it is followed by its translation in quotation marks, such as *Leerás esto* 'You'll read this'. These conventions have been followed in this article.

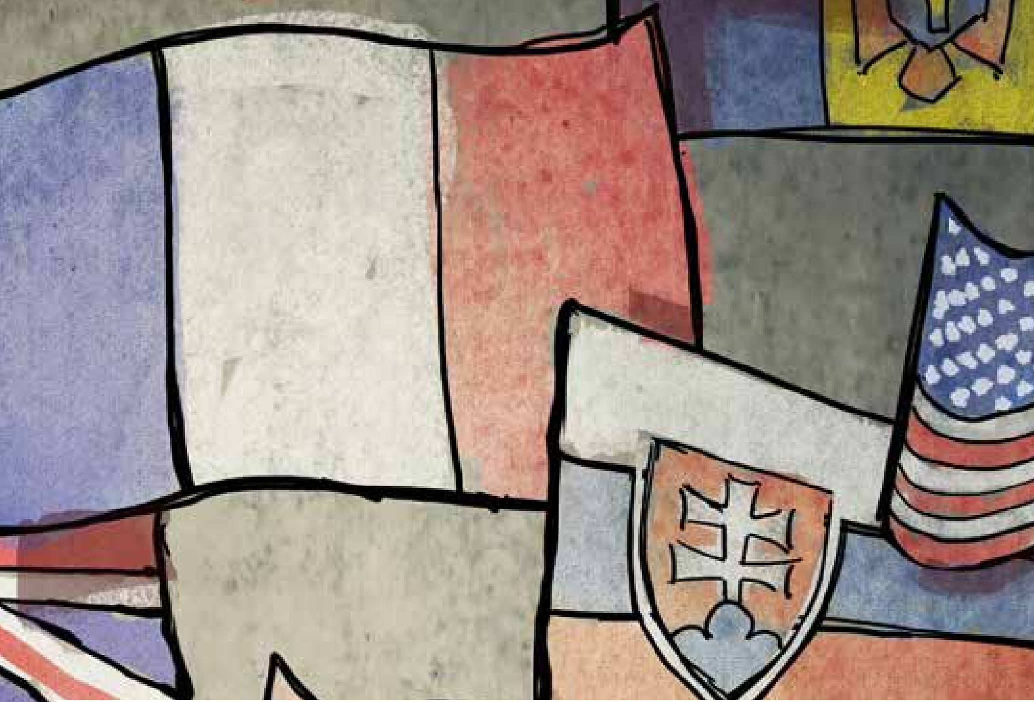
Linguists seek to understand how the brain can make sense of spoken language, which is just a series of sounds. "It is important for scientists to understand how the human mind processes words," says Professor Alice Harris. Alice works in the University of Massachusetts Amherst's Department of Linguistics, where she is interested in deciphering how we process linguistic features called clitics and affixes.

"Clitics are little words that are pronounced with another word," says Alice. "For example, in English, the word *will* can be pronounced as part of another word, as in *She'll know.*" Clitics are related to another linguistic feature called affixes. Affixes are additions to words that alter their meanings, either at the start (prefixes such as *un-* in *unkind*) or the end (suffixes such as *-ing* in *walking*). "Clitics may turn into affixes as language changes," says Alice. "Learning how clitics and affixes are understood by the brain helps us comprehend how the mind processes words."

WHERE IN THE WORD

Linguistics often involves breaking words down into their constituent parts and working out the significance of each and how they interact with one another. "Although clitics have been studied a great deal in terms of sentence structure and sound systems, there has been barely any research into how speakers understand clitics," says Alice. "Our work will reveal some aspects of this."

Alice's team is interested in uncovering whether people's understanding of affixes or clitics varies depending on where the clitics or affixes are placed within the word – before, after or even in the middle. Where these placements occur or how easily they can be compared will vary depending on the language. To better understand this issue, Alice's team



decided to investigate an array of languages with very different structures.

Portuguese presents a good example of this. "In Portuguese, the clitic occurs after the host in *adoramos-te* 'we adore you', but before the host when the phrase is negative, as in *não te adoramos* 'we do not adore you'," explains Alice. This presents a straightforward example of how the researchers can investigate differences in comprehension depending on clitic placement, without many other aspects of the sentence itself changing.

DIVERSE LANGUAGES

Languages vary significantly across the world. Although there are similarities among languages with common roots – Italian and Spanish, for instance, both originate from Latin – there are many languages that are very different from one another. For instance, Mandarin and English have few similarities, in part, because they do not have common roots.

To get a universal understanding of how our brains can make sense of language, research must go beyond just a small subsection of commonly studied languages. "Previous research into affixes has focused on several European languages that are all related and rather similar," Alice explains. "None have very complex word structure, and most have only certain types of structures." To seek a broader understanding, Alice's team has selected some far less-studied languages.

The nation of Georgia is found where Europe meets Asia, in the Caucasus. Its 3.7 million residents mainly speak Georgian, a language that is distinct from more widely used languages. "We selected Georgian because it has a complex word structure and prefix-suffix pairs that can be easily contrasted," says Alice. "For instance, we compared the ease of understanding the prefix *v-* 'I' with the suffix *-s* 'he, she, it', which are placed in different parts of the word – comparing *v-ban* 'I bathe' to *ban-s* 'she bathes'."

Udi is an even less known language, spoken only by a few communities in the Caucasus region, the largest being a village of 4,000 people in Azerbaijan. "We selected Udi, along with European Portuguese, because these languages permit clitics to occur in more positions than other languages," says Alice. "Because of these different positions, we can study how speakers understand clitics when they are in different places relative to the host word. This can't be done with most European languages."

EXPERIMENTS

The team ran several kinds of experiments to gather the information they required. "One experiment involved playing recordings of native speakers saying real words or phrases in different orders, together with nonsense words with real affixes or clitics," says Alice. "The task for the participant was to say whether each was a real word or phrase, or not. We were interested in whether their speed or accuracy changed according to the position of the affix or clitic."

A member of her team, Jack Duff, a PhD student specialising in experimental linguistics, helped research Udi language to prepare for the experiment. The team found the challenges to their research also varied by language.

"Udi is not well-documented," says Alice. "There is a dictionary, and grammar structures are known, but these don't give the whole picture." The team's experiments involved asking native Udi speakers to wear earphones connected to a computer and press keys on a keyboard. "Some participants were not familiar with these instruments," said Alice. "The biggest problem, however, was distractions. As we were conducting these experiments in participants' houses, they would be distracted by children, neighbours or pets."

The team had more success when working in a local school where there were fewer distractions. "For Georgian and Portuguese, however, we had all the language documentation we needed," says Alice. "We also had improvised laboratories for running the experiments." The team also ran a single experiment on English, where they had access to a full psycholinguist's laboratory.

Now that Alice and her team have the data they need, the next step will be to analyse it, prepare their findings and publish their results. Then, the team aims to study even more languages using the same techniques, to see whether people's understanding differs depending on a language's characteristics.

PROFESSOR ALICE HARRIS

Department of Linguistics
University of Massachusetts Amherst, USA

FIELD OF RESEARCH

Linguistics

RESEARCH PROJECT

Studying whether the position of a clitic or affix affects understanding, across different languages

FUNDERS

The project was part of a collaborative project. Alice's research project was funded by the US National Science Foundation (grant number: BCS 1729256) and the University of Massachusetts Amherst

ABOUT LINGUISTICS

Linguistics is a broad field, involving the scientific study of language and how people use it to communicate. Alice explains that there are many areas or specialities within linguistics that can be explored. These include:

- **Phonetics** – the study of how particular speech sounds are made
- **Phonology** – the study of sound systems in particular languages
- **Morphology** – the study of internal structures of words
- **Syntax** – the study of the structure of clauses and sentences
- **Semantics** – the study of the structure of meaning within language
- **Psycholinguistics** – the study of the relationship between linguistic behaviour and psychological processes
- **Computational linguistics** – use of computer modelling to study language
- **Sociolinguistics** – the study of the relationship between language and society
- **Historical linguistics** – the study of how languages change over time
- **Pragmatics** – the study of context and interpretations in a language

Alice explains more about linguistics and why the field is so important for science and culture.

Linguists explore language universals – what characteristics unite all languages? There are many ways of approaching this question. I find the analysis of under-studied languages the most rewarding, because it is from these languages that we learn the most about how human language can vary.

Small languages are disappearing at an alarming rate. Without them, we won't be able to determine the full extent of variation possible in human language. The range of variation informs us about the flexibility of the human brain.

Linguists can document languages by compiling dictionaries, collecting texts and conducting research on grammar. But this is no substitute for preserving a language. Languages only survive if native speakers decide to save the language, but linguists can offer various kinds of expertise and help. In addition to scientific understanding, there are humanitarian reasons for saving languages. Languages are the centre of people's cultural identity, and when a language is lost, the culture is ultimately lost, too.

EXPLORE CAREERS IN LINGUISTICS

• Qualifications in linguistics can lead to a wide array of careers. As well as academia and research, these include communications, teaching, speech therapy, translation and positions within the civil service.

• Alice's department sponsors the Freeman Lecture (**www.umass.edu/linguistics/freeman-lecture**), an annual talk to which local high school students are invited. Their most recent presentation can be found on YouTube: **www.youtube.com/channel/UCqCTKMjThlA7XNI2hr3gzVw.**
Alice mentions that researchers from her department may be open to research projects with interested students.

• According to Indeed, the average annual salary of a linguist in the USA is around $81,000.

PATHWAY FROM SCHOOL TO LINGUISTICS

Linguistics involves skills from arts and science subjects. University courses may look for school qualifications in English language, psychology, computer science or foreign languages.

For a career in an area like her own, Alice recommends skills in mathematics, computer programming and science, as well as foreign languages.

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HOW DID ALICE BECOME A LINGUIST?

I have always been interested in languages. When I was young, this began as an interest in literature.

I became interested in linguistics following a series of lectures. Presented by M. L. Samuels at the University of Glasgow, the lectures got me interested in the history of English, which led on to linguistics.

Linguists need to be able to see patterns in language data. It's important to be highly focused.

In my free time, I enjoy outdoor activities, including cycling, cross-country skiing and, especially, hiking. I spend a lot of time reading. I also write and am working on a memoir, some stories and some poems.

> **"Linguists need to be able to see patterns in language data. It's important to be highly focused."**

MEET JACK

JOHN (JACK) DUFF

Department of Linguistics at the University of California Santa Cruz

Professor Harris recruited me as a research assistant after I took a class she taught. Our research was in Azerbaijan, where I worked with Professor Harris and local consultants to identify the verbs to use in our experiment and record the consultants saying these verbs.

This was one of the first experiments I helped run. It was also the first time I had worked with native speakers to learn and study a language I didn't speak myself. Presently, as a PhD student, I use these same methods to investigate similar questions. By using experimental tools and working with native speakers around the world, we can look beyond the structures of individual languages, and learn more about the universal patterns that really interest us.

In my other research, I study semantics and pragmatics. This is where questions about the structure of language meet questions about how we use language in the real world. The same sentence can have an entirely different meaning in a different context! My research investigates these differences and tries to understand how they fit into our existing knowledge about language.

My interest in language came from studying Latin in school. Learning Latin's complicated structure led me to pay more attention to the complexities of my native language, English. That curiosity has persisted, leading to studying linguistics in college and, eventually, to answering language-related research questions as a PhD student.

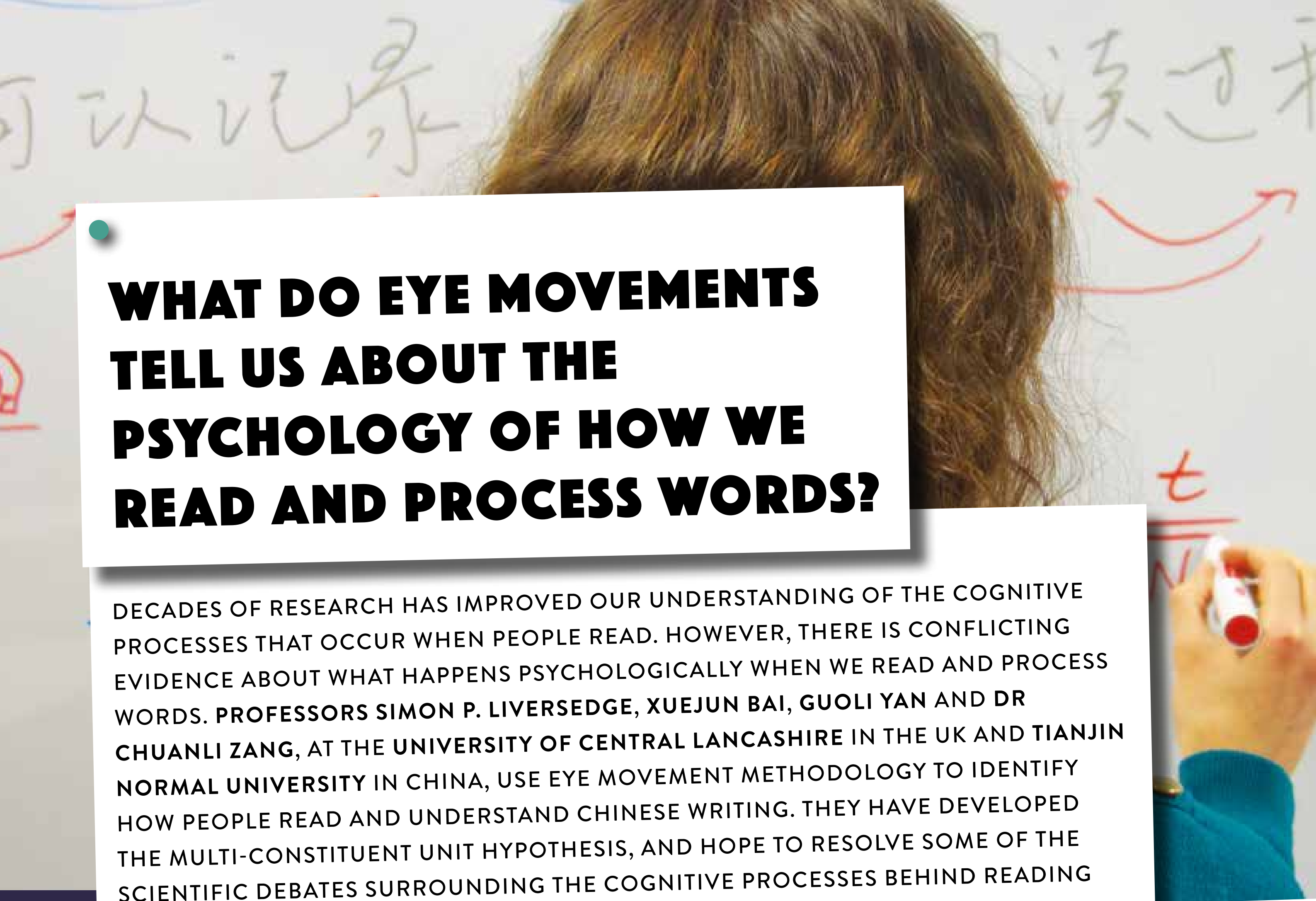
It's useful for a linguist to be curious about why people say and write the things they do. There are times when a friend has said something in conversation, and the words or sentence structure they use has shown me something new. I can then grab a pen and start asking lots of related questions – so, it's also useful to have patient friends!

As a PhD student, I'm developing new research questions and practising teaching others about what I study. I hope to keep doing these things in the future, as a professor or as a linguist working in related fields in science or technology.

ALICE AND JACK'S TOP TIPS

01 Explore whatever aspects of language interest you – phonetics (the study of how particular sounds are made), phonology (the study of sound systems in particular languages), morphology (the study of the internal structure of words), syntax (the study of the structure of clauses and sentences), semantics (the study of the structure of meaning), computational linguistics, sociolinguistics, historical linguistics and more.

02 Be curious about how you and other people use language. Ask yourself questions like, "How does it change this sentence if I say the words 'a dog' instead of 'the dog'?" or "Why does it sound so funny to say `The train arrived for two hours'?" A well-developed sense of curiosity is the most important tool in any scientist's toolbox.



WHAT DO EYE MOVEMENTS TELL US ABOUT THE PSYCHOLOGY OF HOW WE READ AND PROCESS WORDS?

DECADES OF RESEARCH HAS IMPROVED OUR UNDERSTANDING OF THE COGNITIVE PROCESSES THAT OCCUR WHEN PEOPLE READ. HOWEVER, THERE IS CONFLICTING EVIDENCE ABOUT WHAT HAPPENS PSYCHOLOGICALLY WHEN WE READ AND PROCESS WORDS. **PROFESSORS SIMON P. LIVERSEDGE, XUEJUN BAI, GUOLI YAN** AND **DR CHUANLI ZANG**, AT THE **UNIVERSITY OF CENTRAL LANCASHIRE** IN THE UK AND **TIANJIN NORMAL UNIVERSITY** IN CHINA, USE EYE MOVEMENT METHODOLOGY TO IDENTIFY HOW PEOPLE READ AND UNDERSTAND CHINESE WRITING. THEY HAVE DEVELOPED THE MULTI-CONSTITUENT UNIT HYPOTHESIS, AND HOPE TO RESOLVE SOME OF THE SCIENTIFIC DEBATES SURROUNDING THE COGNITIVE PROCESSES BEHIND READING

TALK LIKE A COGNITIVE PSYCHOLOGIST

COGNITIVE – related to mental processes such as thinking, understanding, learning, and remembering

LINGUISTIC – related to language

EYE MOVEMENT METHODOLOGY – the process of measuring the movements of the eyes, usually using an eye tracking device

FOVEAL VISION – vision within a central part of the eye called the fovea, where the eye is best able to distinguish shapes and details

PARAFOVEAL VISION – vision within the parafoveal region of the eye which surrounds the fovea, where the eye's ability to distinguish shapes and details is comparatively reduced

HYPOTHESIS – a proposed explanation for something that has not yet been fully explained, which can be tested by scientific methods

MILLISECOND (MS) – one thousandth (0.001) of a second

SACCADE – a rapid rotation of the eyeballs

Over the past few decades, research into the cognitive processes linked to reading has improved the way we teach children to read. However, there are still unresolved scientific debates about how people process text when they read.

A lot of previous research has focused on alphabetic writing systems like English. Chinese is different to alphabetic writing systems because it is character based, unspaced and has unclear word boundaries (see box on **THE CHINESE WRITING SYSTEM**). Studying written Chinese, therefore, enables cognitive psychologists to investigate questions that are impossible to research in other writing systems. Professors Simon P. Liversedge, Xuejun Bai, Guoli Yan and Dr Chuanli Zang, from the University of Central Lancashire and Tianjin Normal University, use eye movement methodology to understand reading of Chinese. Based on these experiments, they have developed a new hypothesis called the Multi-Constituent Unit hypothesis, which may explain some of the gaps in our understanding of the cognitive psychology of reading.

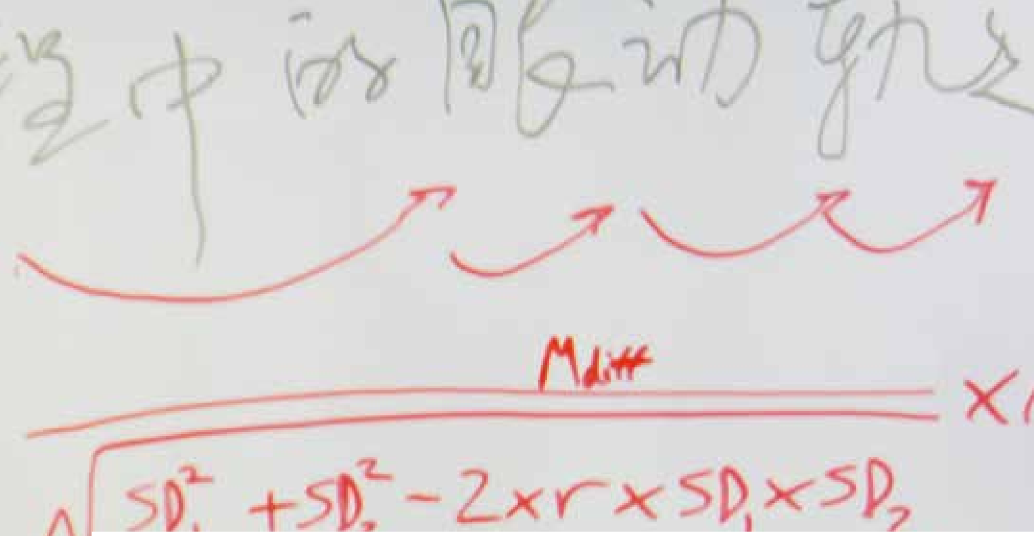
HOW DO OUR EYES MOVE WHEN WE READ?

"Patterns of eye movements reflect moment to moment cognitive processes that occur as a reader understands text," Chuanli explains. Using eye tracking experiments, scientists have established that we do not sweep our eyes smoothly across a sentence when we read. Instead, we alternate between rapid eye movements called saccades which last 10-50 ms followed by fixations – periods of around 200-250 ms when our eyes stay relatively still – to extract visual information about each of the words we are reading.

When words are in foveal vision, very detailed information is encoded, which allows the words to be fully processed and identified. Words in the parafovea are partially processed. Saccades bring the words in the parafovea into foveal vision. Readers do not fixate on all words – they sometimes skip them, making a saccade over them.

WHAT SCIENTIFIC QUESTIONS ABOUT EYE MOVEMENTS ARE STILL UNANSWERED?

There is still debate about how words are processed when people read. Simon says that a key scientific question is: "are multiple words lexically identified at the same time, or are they identified one by one?" This debate has, so far, been informed mainly by studies investigating reading of alphabetic writing systems such as English. Understanding how



PROFESSOR SIMON P. LIVERSEDGE

DR CHUANLI ZANG

School of Psychology and Computer Science, University of Central Lancashire, UK

PROFESSOR XUEJUN BAI

PROFESSOR GUOLI YAN

Faculty of Psychology, Tianjin Normal University, China

FIELD OF RESEARCH

Cognitive Psychology

RESEARCH PROJECT

Investigating the Multi-Constituent Unit (MCU) hypothesis – seeking to understand cognitive processes behind reading to help resolve key scientific debates and inform better educational practices

FUNDER

Economic and Social Research Council Grant (ES/R003386/1)

THE CHINESE WRITING SYSTEM

- Chinese writing is based on characters rather than an alphabet.
- Each character consists of strokes with simple features like dots, lines and curves which are put together to form sentences e.g. 十种方法让学习变得简单有趣 means 'ten ways to make learning easy and enjoyable'.
- Chinese words are one, two, three or more characters long.
- There are no spaces between characters and words – the writing system is described as 'unspaced' – so Chinese readers must make decisions about where word boundaries lie as they read a sentence. This is a cognitive process called 'word segmentation'.
- Word segmentation is not always clear, and it is quite common for Chinese readers to disagree about where the word boundaries in a sentence lie.
- The distinction between words and phrases can also be unclear. For example 简单有趣 means 'easy and enjoyable' – a phrase in English, but this is sometimes segmented as a word by Chinese readers. In fact, the Chinese did not have a term for 'word' until the beginning of the 20th century.
- Different segmentations sometimes result in confusing interpretations, for instance when we segment the sentence as follows: 武汉市|长江大桥|欢迎|您 it means 'Wuhan city|Yangtze river bridge|welcomes|you'; but if we segment it as follows: 武汉|市长|江大桥|欢迎|您 it means 'Wuhan city|major|Jiangdaqiao|welcomes|you'.

people read non-alphabetic, unspaced writing systems like Chinese, allows us to investigate an important gap in current understanding. However, as words are not clearly segmented in Chinese, this challenges scientists to consider whether research questions about the order in which words are read are applicable to this writing system, and which questions we need to ask to understand cognitive processes related to reading.

HOW CAN EXPERIMENTS HELP US TO UNDERSTAND READING CHINESE?

The team uses an eye tracker, which measures people's eye movements while they read. The device is positioned in front of a research participant who sits and reads sentences from a computer screen. The tracker records the reader's eye position (and the particular letter or character the reader is fixating on) every millisecond to give a very precise indication of where the reader is looking.

Data are recorded on eye position, the duration of fixations, the time readers spend processing a word, how often readers skip a word and whether readers make right-to-left movements to re-read portions of sentences. These factors indicate which parts of the text are more difficult to read. The team then does statistical analyses of the data.

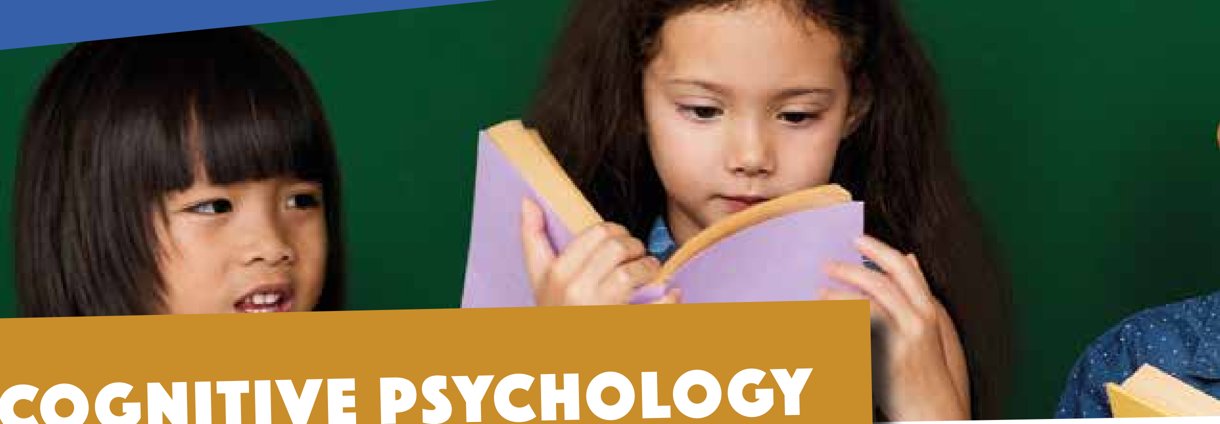
WHAT IS A MULTI-CONSTITUENT UNIT?

The Multi-Constituent Unit (MCU) hypothesis was developed by Simon, Chuanli and their colleagues based on their eye movement experiments. It may explain why experiments suggest that when people read, on some occasions, multiple words are identified at the same time, and, on other occasions, words are identified one by one. "The idea is that some frequently occurring linguistic units are made up of more than a single word. For example, spaced compound words like 'teddy bear', and common phrases like 'salt and pepper'," explains Chuanli. These MCUs may be processed as if they were single words, which could result in more than one word being processed at the same time (i.e. 'teddy' and 'bear' may be processed at the same time, rather than one after the other, because they are identified as a single word).

The team has carried out more than ten experiments supporting their MCU hypothesis. It has shown that frequently used Chinese phrases, expressions, famous people's names, place names, product names and popular phrases (many from social media), are often processed as MCUs during reading.

WHAT IS THE WIDER IMPORTANCE OF THIS RESEARCH?

This research expands scientific knowledge of cognitive processes related to reading, contributing to understanding in psychology, linguistics and education, with practical implications for society. For example, understanding how MCUs are learned and segmented can help children and adults learning to read Chinese. Simon says, "Ultimately, our work has the potential to influence educational best practice related to teaching, literacy development and support for those with learning difficulties."



ABOUT COGNITIVE PSYCHOLOGY

Cognitive psychology is the study of mental processes related to how people perceive, recognise, read, learn, remember and think about information. To understand these processes, cognitive psychologists use a range of scientific research methods: proposing research questions, generating hypotheses, collecting data, analysing data, developing theory, and sometimes applying the implications of research findings to practical settings.

Cognitive psychologists, like other academics, often teach university students about what they have discovered and why it is important. This motivates students to think about pursuing a research career of their own and carrying out future experiments that will further develop scientific understanding. Simon says, "Having an opportunity to teach and inspire students is very rewarding."

IMPACTING SOCIETY

Understanding mental processes can help us improve the way society functions in relation to those processes. For example, scientific investigations of reading over the past few decades have led to the development of evidence-based educational policy to improve teaching. "It is very rewarding to know that the research we undertake directly impacts how children in schools are taught to read," says Chuanli.

COLLABORATIONS

Teamwork between scientists in the UK and China enables research on cross-linguistic and cross-cultural issues. Simon has worked with Xuejun, Guoli and Chuanli, as well as other colleagues at Tianjin Normal University (TNU) for over 15 years. He says, "Without this collaborative relationship, our research, which informs our understanding of reading and other cognitive processes, would not have been possible."

The relationship has had other benefits, such as enabling exchanges so that students and staff can experience working in a research lab in another country. "International collaborations lead to cultural exchange and friendships that are long lasting and important," says Chuanli.

LOOKING AHEAD

The team thinks that eye movement methodology will continue to be an important feature of cognitive psychology in future. Another developing area of research involves combining this methodology with real-time measurements of brain activity. Using these techniques at the same time will enable scientists to better understand the links between brain activity and the cognitive processes occurring while visual tasks, like reading, are being performed.

Although there has been a lot of research to investigate reading in English, Simon points out that there has been comparatively less work to investigate how people read other writing systems. This is particularly true for non-alphabetic writing systems like Chinese, so there is a need for more research exploring reading in these writing systems.

EXPLORE CAREERS IN COGNITIVE PSYCHOLOGY

- University outreach programmes can help you to learn more about life as a cognitive psychologist. For example, the University of Central Lancashire (UCLan) offers school visits to the cognitive psychology labs, and there will be psychology information sessions coming to UCLan's Young Scientist Centre: **www.uclan.ac.uk/about-us/schools-and-colleges/young-scientist-centre**

- Simon, Chuanli and colleagues also attend the annual Lancashire Science Festival (**lancashiresciencefestival.co.uk/**), where they give talks explaining fascinating psychological experiments.

- The British Psychology Society (**www.bps.org.uk**) and the Experimental Psychology Society (**eps.ac.uk**) provide useful information about cognitive psychology and related career paths.

- In the UK, the average salary of a psychologist ranges from about £30,000 to £90,000 per year (**nationalcareers.service.gov.uk/job-profiles/psychologist**).

PATHWAY FROM SCHOOL TO COGNITIVE PSYCHOLOGY

- Generally, to be a cognitive psychologist, you will need an undergraduate degree in psychology. After this, it is also usually necessary to obtain a master's degree and PhD.

- To become a chartered psychologist, you need to take a course accredited by the British Psychology Society (**www.bps.org.uk/join-us/membership/chartered-membership**).

- You must study maths or at least one science subject (such as biology, physics or chemistry) at school to be eligible for many psychology undergraduate degrees. However, entry requirements vary depending on the university.

- Simon also advises that because scientists must publish their findings, solid English skills are very important.

HOW DID SIMON AND CHUANLI BECOME COGNITIVE PSYCHOLOGISTS?

SIMON P. LIVERSEDGE

CHUANLI ZANG

Both Simon and Chuanli were interested in science and nature when they were younger. Another similarity is that they were both intrigued by what humans do mentally in their daily lives.

Simon: "I worked hard at school, then did my A-levels before becoming an undergraduate student at the University of Dundee. There, I conducted an eye movement experiment to investigate reading for my dissertation and through this became interested in this area. I was fortunate to secure competitive funding to support my research for my PhD and then went on to work for several years as a Postdoctoral Research Fellow in Nottingham University. After this, I took a position as a lecturer at Durham University before moving to be a professor at the University of Southampton. During this time, I developed links with colleagues in China, working closely with Xuejun and Guoli."

Chuanli: "I also worked very hard at school! I attended Yantai Normal University (now Ludong University) where I studied for my degree in psychology. I moved to Tianjin Normal University to take my master's degree and PhD, where I was supervised by Xuejun. During the PhD, I decided to visit the UK to work with Simon and applied for a China Scholarship Council award to allow me to do so. I first met and started working with Simon during my first visit to the UK. Simon and I then China wrote a successful grant application which allowed us to undertake the research project investigating Chinese reading, and now I work with him at the University of Central Lancashire as a research fellow. We both still work closely with Xuejun and Guoli in Tianjin, and we try to visit China on work trips, when we can."

As they progressed through education and research, Simon and Chuanli were both inspired by many great researchers working in cognitive psychology. In particular, Professor Keith Rayner – a pioneer in making eye movement methodology, a major tool for studying cognitive processes – inspired them to pursue their research.

Simon and Chuanli say that it is through perseverance, ambition and hard work that they have become successful scientists. They are very proud of their work, especially their international collaborative research carried out between China and the UK.

SIMON AND CHUANLI'S TOP TIPS

"To follow in our footsteps, there are two key ingredients for (100%) success:

01 Maintain strong motivation to achieve your goals (20%)

02 Work very hard (80%)!"

Chinese characters develop over time
Question: can you guess the meaning of these characters? Hint, they are all animals. See back page for answers.

UNESCO: BREAKING DOWN GENDER SEGREGATION IN STEM IS GOOD FOR INNOVATION, ECONOMIES AND THE SUSTAINABILITY OF OUR PLANET

IN 2017, **UNESCO** PUBLISHED **CRACKING THE CODE: GIRLS' AND WOMEN'S EDUCATION IN SCIENCE, TECHNOLOGY, ENGINEERING AND MATHEMATICS.** ITS AIM WAS TO DECIPHER THE FACTORS THAT HINDER OR FACILITATE GIRLS' AND WOMEN'S PARTICIPATION, ACHIEVEMENT AND CONTINUATION IN STEM EDUCATION. FIVE YEARS ON, WE ASK **JUSTINE SASS**, CHIEF OF THE SECTION OF EDUCATION FOR INCLUSION AND GENDER EQUALITY, HOW MUCH HAS CHANGED SINCE THE REPORT'S PUBLICATION

HAVE WE SEEN IMPROVEMENTS IN THE REPRESENTATION OF GIRLS AND WOMEN IN STEM SINCE THE PUBLICATION OF *CRACKING THE CODE?*

In *Cracking the Code*, we were looking at several things related to girls' participation and learning in STEM. First, we were looking at learning achievement in STEM subjects and how girls were doing compared to boys at different levels of education. Second, we reviewed young women's enrolment and completion in STEM fields in higher education.

Let's start with improvements in learning since our report. There are no science assessment data in low-income countries, but girls are now outperforming boys in science in secondary school in the majority of middle- and high-income countries. This is particularly the case in the Arab States where the percentage of girls achieving minimum proficiency in science exceeds that of boys by 15 points in countries like Bahrain and Saudi Arabia at Grade 4, and by 21 points in Bahrain, Jordan and Oman among Grade 8 students.

The gender gap in mathematics is also shrinking. While boys in most middle- and high-income countries tend to perform better than girls in mathematics in the early grades, on average, they do not have an advantage later. The gender gap is reversed to favour girls, for example, among Grade 8 students in Bahrain (8 points), Jordan (7 points), Oman (13 points), Romania (8 points) and Turkey (5 points). This being said, in 50 of 54 countries, girls are less likely to get top marks in mathematics, despite performing better than boys at school overall. Gender stereotypes, low levels of self-confidence in these subjects, and other inequalities still prevent girls from realising their full potential.

In terms of higher education, the share of women in the student population has continued to rise; in 2020 there were 113 women for every 100 men enrolled in higher education. While the share of women graduates in scientific fields continues to increase in all developing regions (except Latin America and the Caribbean, where their participation was already high), women are still less likely to major in other aspects of STEM such as engineering, manufacturing or construction, and ICT studies. And these gaps are the widest in low-income countries. This will take time to change, as we have to fill the pipeline – getting new generations of women students to take up these studies and complete their degrees.

A UNESCO programme in Tanzania expanding access to online tools and digital skills, connecting girls to learning and the world around them. © UNESCO Dar es Salaam/ Kimlong Meng

A UNESCO programme works with non-formal educators to build the digital skills of indigenous adolescents and young women in Guatemala. © UNESCO Guatemala/Armando Velásquez

> **"IT MEANS UNLEASHING THE POWER OF EDUCATION TO TACKLE THE UNEQUAL POWER RELATIONS, SOCIAL NORMS, DISCRIMINATORY PRACTICES AND BELIEF SYSTEMS THAT UNDERPIN GENDER INEQUALITY AND EXCLUSION IN SOCIETY."**

While we cannot comment on these changes yet, what we can say is that there has been a growing push to improve women's participation and experience in STEM. Rwanda has been a trailblazer in championing women in STEM, including a commitment to triple the number of girls in these fields. Costa Rica established a National Policy for Equality between Women and Men in Training, Employment and Enjoyment of the Fruits of Science, Technology, Telecommunications and Innovation (2018–2027). In the United States, many private companies working in science, engineering and technology are making hiring a diverse workforce, including greater representation of women, a pillar of their annual strategies. And there are growing efforts by women's colleges and universities to educate women in STEM, including the Kiri Women's University of Science and Technology in Kenya, the Women's Institute of Technology in India, and many women's colleges in the United States. Many educators have been looking to these examples to inform women's participation and experience in STEM fields at co-educational institutions.

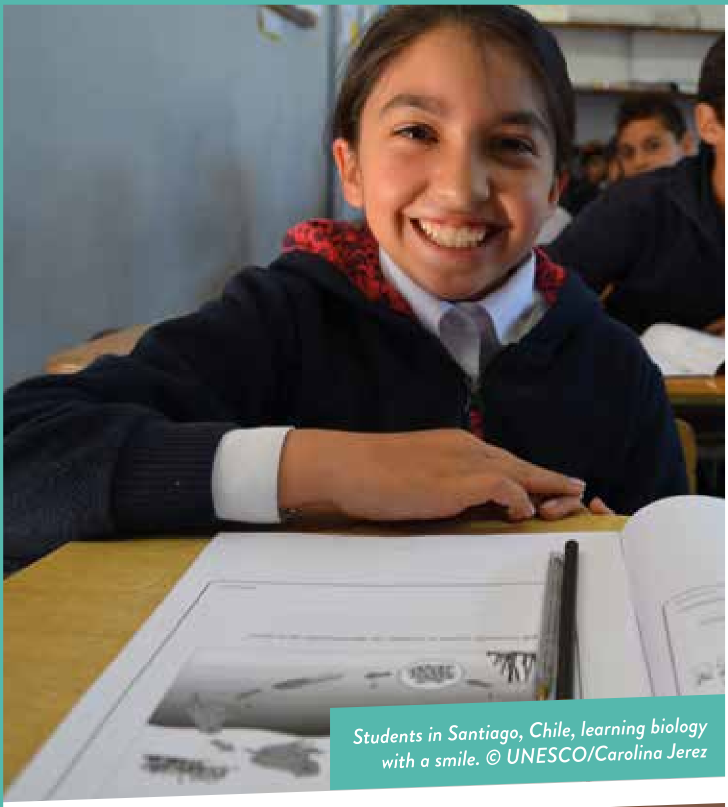
We need to keep monitoring progress, documenting good practice, and catalysing cooperation to scale up these and related efforts to get more women into STEM.

HAS THE REPORT ACHIEVED ITS AIM TO STIMULATE DEBATE AND INFORM STEM POLICIES AND PROGRAMMES AT GLOBAL, REGIONAL AND NATIONAL LEVELS?

Definitely, and we have continued to cooperate with other organisations to leverage progress. This includes the African Union's International Centre for Girls' and Women's Education and their efforts to gender-responsive STEM policies and programmes across the continent. We are also collaborating with the International Association for the Evaluation of Educational Achievement (IEA) which supports learning assessments in science, maths and technology in over 60 countries, on a series of policy briefs to inform STEM programmes at the country level, based on evidence. We are supporting countries like Uganda to develop national guidelines on gender-responsive pedagogy, linked to its National Teacher Policy, which includes strategies to enable girls and boys to fully participate and achieve in STEM subjects. We continue to accompany countries in their efforts to ensure inclusive and equitable quality education to advance girls' participation in STEM.

WHY IS UNESCO SO INVESTED IN THIS ISSUE?

UNESCO prioritises efforts to advance gender equality, and the realisation of gender equality in and through education. This means more than just having equal numbers and proportions of girls and boys in different levels of education, although this is an important starting point. It means unleashing the power of education to tackle the unequal power relations, social norms, discriminatory practices and belief systems that underpin gender inequality and exclusion in society. It's an education that considers the needs, interests and lived experiences of all learners, and which tackles the intersecting and simultaneous disadvantages that may inhibit them from fully exercising their right to participate in, complete and benefit from education.



Students in Santiago, Chile, learning biology with a smile. © UNESCO/Carolina Jerez

UNESCO training in Senegal helps teachers learn how to use materials around them to create low-cost engaging experiences for girls. © UNESCO/Justine Sass

We believe in breaking down the gender segregation that exists in educational pathways and careers, and that getting more girls and women in STEM fields isn't only good for them, it's good for innovation, economies, the development of entire countries and for the sustainability of our planet.

THE REPORT STATES THAT "EDUCATION SYSTEMS AND SCHOOLS PLAY A CENTRAL ROLE IN DETERMINING GIRLS' INTEREST IN STEM SUBJECTS." ARE SCHOOLS MORE INTEGRAL TO THIS ISSUE THAN POLICY CHANGES, FOR EXAMPLE?

The report shows that it's not schools or education systems alone that determine whether or not a girl will pursue STEM studies or careers. Girls' own interests and motivations, as well as parents, peers and other influences are also important. But schools are where children and young people spend such a significant part of their lives. Schools are where they often have the most exposure to STEM subjects, both through formal education and extra-curricular opportunities. It's in schools, typically, where children and youth develop their own perceptions of their potential in STEM studies, where they begin to understand what careers in STEM could look like, and where educational and careers pathways begin to take shape. Schools are also important bridges to parents, communities, apprenticeships, mentorship and other opportunities to transition into the workplace and society. As such, schools really are important.

WHAT IS UNESCO DOING TO SUPPORT SCHOOLS?

We have a multi-pronged strategy to advance girls' and women's participation in STEM. There are a lot of pieces to this puzzle, let me share some of these:

- **Data and evidence:** You can't find a solution if you don't know that you have a problem, and you can't celebrate success if you don't know that it exists! UNESCO supports the collection and use of data to inform action. This includes supporting countries to deliver learning assessments in maths and science that help them understand who is learning and who isn't, and the factors that support learning and achievement. Beyond *Cracking the Code*, we have also looked specifically at efforts to get more girls and women into STEM in Asia and in technical and vocational educational and training programmes.

Three girls in Nairobi, Kenya, show Justine what they enjoy doing in their Science Lab. © UNESCO

Two girls standing in front of their Physics Lab in Kigali, Rwanda. © UNESCO/Justine Sass

> "RWANDA HAS BEEN A TRAILBLAZER IN CHAMPIONING WOMEN IN STEM, INCLUDING A COMMITMENT TO TRIPLE THE NUMBER OF GIRLS IN THESE FIELDS."

• **Capacity development:** UNESCO supports countries to build the national and institutional capacities to deliver gender-responsive STEM education where all children can learn, grow and develop to their full potential. In sub-Saharan Africa, UNESCO has worked with Ministries of Education, the African Union, and other partners in over 20 countries to build the capacity of teachers, teacher trainers and school administrators, and close gender gaps in these fields. In Niger, an estimated half a million students (40% of whom are girls) now have access to gender-responsive pedagogy. If you'd like to hear what the girls have to say about this, listen to Angel and Fatma from Tanzania: **www.youtube.com/watch?v=MAoujwmQ0j8**

• **Policy:** UNESCO supports countries to improve their policy and legislative frameworks to advance girls' right to education, including educational pathways in STEM. For example, UNESCO supported Uganda to develop national guidelines on gender-responsive pedagogy, which includes strategies to enable girls and boys to fully participate and achieve in STEM subjects. It is helping thousands of girls participate more actively in the classroom, leading to better learning outcomes and a brighter future for girls.

• **Mentoring and role models:** Role models and mentors have been found to be particularly effective in tackling gender bias. They offer girls an authentic understanding of STEM studies and careers, showing them that they, too, can become who they dream of becoming. UNESCO has supported STEM camps and school-based clinics where girls have access to role models and mentors in STEM in countries across the globe. In Kenya, during the COVID-19 pandemic, UNESCO supported the country's STEM mentorship programme to go digital through radio and online platforms, reaching 12 million listeners in the first three months alone. UNESCO also amplifies what girls are doing themselves to be role models and support learning, like Deepa from Nepal: **www.youtube.com/watch?v=HQvryT3todA**

ONE OF THE KEY STRENGTHS OF THIS REPORT IS THE IDENTIFICATION OF INTERVENTIONS THAT PROMOTE GIRLS' AND WOMEN'S INTEREST IN AND ENGAGEMENT WITH STEM STUDIES. ARE THESE INTERVENTIONS STILL RELEVANT FIVE YEARS ON?

Definitely, but the way we are delivering them has had to evolve, particularly in the context of COVID-19 extended school closures where school-based interventions were unable to be delivered.

We believe in an ecosystem of interventions that address the factors holding girls back from pursuing these fields. This requires engagement not only with girls, but also with parents, their peers in schools, teachers, principals and other school staff, and community and media influencers. Some of these interventions include:

- Linking girls to female role models and mentors to build their interest in and understanding of STEM careers, and to break stereotypes that STEM studies and careers are not for women.
- Building teacher capacity at all levels of education to understand and address unconscious bias in the teaching practice, to engage all learners equally, and to create an inclusive, dynamic and safe learning environment.
- Removing gender stereotypes and bias in STEM curricula, textbooks and learning materials, ensuring visibility of women STEM innovators and leaders, and closing gender gaps in digital access and skills.
- Expanding girls' access to scholarships, fellowships, competitions and prizes that address financial constraints to their participation and can draw them into higher education programmes in these fields.
- Establishing and implementing policies and legislation that support equal education and career pathways, and zero discrimination in these fields.

IF THERE IS ONE THING SCHOOLS OR TEACHERS COULD BE DOING TO TACKLE UNDER-REPRESENTATION IN STEM, WHAT SHOULD IT BE?

This is a really difficult question, as we believe that there isn't really a magic bullet or one single action that will tackle girls' under-representation in STEM. At UNESCO, we think this needs action within and beyond school walls to reach across sectors and engage girls and women, boys and men to identify solutions to local challenges.

I guess if I were pressed to choose one action at the school level, I would say invest in teachers. Beyond parents, teachers can be one of the most important influencers in a child's life. We need to invest in teachers' capacities, confidence and subject expertise in STEM and their ability to create equal learning pathways for girls and boys. We need to recruit more women teachers in these fields to break stereotypes and to serve as role models for both boys and girls. And we need to ensure teachers have the support systems and resources they need to change harmful gender norms, expectations and stereotypes that hold girls back from learning and participating in STEM.

ARE THERE ANY UPCOMING UNESCO PROGRAMMES TEACHERS AND STUDENTS SHOULD KNOW ABOUT?

UNESCO played a leading role in supporting preparations for the Transforming Education Summit that took place mid-September 2022 under the leadership of the United Nations Secretary-General at the United Nations in New York.

The Summit was convened in response to a global crisis in education – one of equity, inclusion, quality and relevance. Its aim was to mobilise ambition, solidarity and solutions to recover pandemic-related learning losses and sow the seeds to transform education in a rapidly changing world. This includes steering digital transformation to promote just and equitable learning, addressing educational exclusion and gender inequality, and supporting the financial investments needed to ensure no one is left behind. It's part of a new vision for the future of education. It isn't a meeting, it's a movement and well-worth following and contributing to: **www.un.org/en/transforming-education-summit**

WHAT ARE YOUR HOPES FOR THE FUTURE?

Cracking the Code has helped countries and organisations understand the factors holding girls back from education and careers in STEM fields, and what we need to do to improve the interest, engagement and achievement of girls in these fields. It has provided UNESCO with a strong foundation for further policy and technical support to countries, and catalysed many partnerships, commitments and actions to take forward the work. Our hopes remain the same as they have always been: Girls and women are key players in crafting solutions to improve lives and generate inclusive and sustainable development that benefits us all. They are the greatest untapped population to become the next generations of STEM professionals – we must invest in their talent.

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MORE RESOURCES

Read *Cracking the Code: girls' and women's education in science, technology, engineering and mathematics (STEM)*

unesdoc.unesco.org/ark:/48223/pf0000253479

Read *STEM education for girls and women: breaking barriers and exploring gender inequality in Asia*

unesdoc.unesco.org/ark:/48223/pf0000375106

Read *Boosting gender equality in science and technology: a challenge for TVET programmes and careers*

unesdoc.unesco.org/ark:/48223/pf0000374888

MEET JUSTINE

Chief, Section of Education for Inclusion and Gender Equality, UNESCO

I've always been interested in how public policy enhances or restrains opportunity. In high school, I watched the fall of the Berlin Wall. In my college years, I saw the end of apartheid in South Africa, and the rise of Nelson Mandela to power. I had naïve, young dreams of being part of the serious change happening in the world around me. Studying political science at university seemed to be the right path to me at the time.

I didn't really have a clear career goal in mind. I knew I wanted a job that pushed for social change, equality and rights. I wasn't so clear on how to do that, though, or what jobs in those fields looked like. The internet wasn't a thing when I started university – our understanding of possible careers was so very limited. I went into the Peace Corps within a week of the end of university with the hopes that it would give me a bigger vision of what was possible.

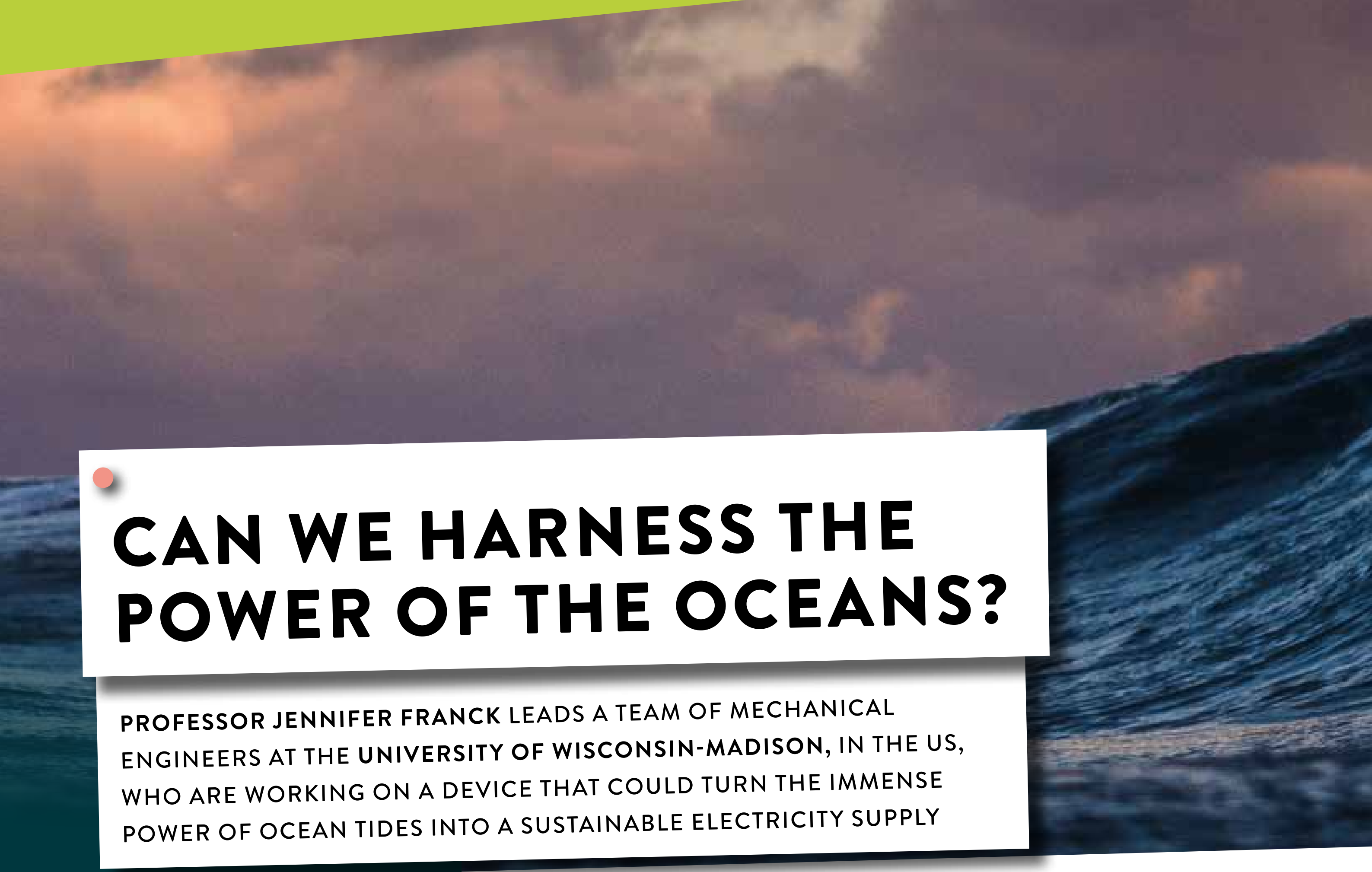
What I love most about the work I do is the people – those who work beside me and those whose lives we aim to impact. My colleagues are all passionate about the issues we work on and are driven more by that than by anything else. It's inspiring and nourishing to come to a job that aims to catalyse change, and to support equal opportunities for learning and equal futures for all.

Interacting with those we aim to support is even more inspirational for me. It's harder to see in my current job in a Headquarters post, as we are several levels removed from the field work, but when I go out for project visits to exchange with our Ministry and other partners, or to hear from our young learners and activists on the challenges they are facing and the brilliant efforts they're making, this is really the golden nugget. Change can sometimes feel slow and hard, like two steps forward and another one back, but it's really worth the effort.

My one piece of advice is you can be anything you want but it might take some time to figure that out so don't rush it. Don't be discouraged if you're not sure yet, or if the advice you get from your parents, school counsellors or anyone else doesn't quite fit with your mindset or dreams or, for that matter, your uncertainty! You have your whole life ahead of you. Take the first step towards the life you want to live – the next steps will follow.

CONNECT WITH JUSTINE

www.linkedin.com/in/justine-sass-b52a7691



CAN WE HARNESS THE POWER OF THE OCEANS?

PROFESSOR JENNIFER FRANCK LEADS A TEAM OF MECHANICAL ENGINEERS AT THE **UNIVERSITY OF WISCONSIN-MADISON**, IN THE US, WHO ARE WORKING ON A DEVICE THAT COULD TURN THE IMMENSE POWER OF OCEAN TIDES INTO A SUSTAINABLE ELECTRICITY SUPPLY

TALK LIKE A MECHANICAL ENGINEER

RENEWABLE ENERGY – a source of energy that will never run out

LIFT – when fluid flows around an object, lift is a resulting force that is at right angles to the direction of the flow

MARINE ENERGY – energy derived from oceans and tides

TIDAL ZONES – narrow land constrictions that experience both high and low tides

OSCILLATE – to move back and forth in a regular rhythm

ROTATE – to move in a circular motion

Have you ever tried to stop the tide coming in at the beach by building your best sandcastle? If so, you will know how hard it is to halt the sea in its tracks. Twice a day, every day, the irresistible pull of the moon's gravity forces the world's oceans to rise – pouring up the beaches, rushing into inlets, crashing into cliffs – only to fall back down again.

Imagine you had the power of the tide at your fingertips. Imagine, at the flick of a switch, you could transform that surging water into electric energy for your phone, light for your living room, or heat to cook your dinner. This is the goal of Professor Jennifer Franck. As a mechanical engineer at the University of Wisconsin-Madison, she has been pioneering technology that could one day make our electricity supply more sustainable and more reliable.

WHERE DOES OUR ENERGY COME FROM?

These days, it is the power of fossils. Most of the energy used around the world (about 85% in 2020) comes from coal, oil and gas – all of which are the fossilised remnants of plants and animals that lived millions of years ago. However, these fossil fuels are not renewable, and their use is causing climate change through the release of carbon dioxide, so it is crucial that we shift to different sources of energy soon.

You may have spotted the white spinning blades of wind turbines on a hillside, or seen rooftops covered in black, shiny solar panels. These technologies turn the power of the wind and sun into electricity and are being built rapidly around the world. Together, they now make up around 5% of the US's energy mix.

Marine energy, on the other hand, is yet to make a big impact. It was not until 2008 that the first marine power plant was connected to the grid in Northern Ireland, and, since then, only a few more have appeared. Most technologies for capturing marine energy (including ocean currents and waves as well as tides) are still being developed by scientists and engineers such as Jennifer.

WHY USE MARINE ENERGY?

As wind and solar power technologies are becoming cheap and widely available, you might be wondering why we need marine energy at all. The wind and sun are both renewable, and capturing their energy does not release carbon dioxide into the atmosphere, so why bother developing new technology for the oceans where we have to deal with corrosive saltwater and challenging logistics of installation and maintenance? The answer is all about reliability and predictability.

Take a look outside: how is the weather? Is the sun shining? Is the wind blowing? Imagine you could only turn on your TV if it was windy enough to spin your local wind turbine! Now think about what the weather will be like tomorrow: will there be an overcast sky? What impact could thicker cloud cover have on solar energy output?

We need energy every day, but wind and solar rely on unpredictable weather conditions to work, so if we were to use only these sources, we would need to build up enormous energy reserves to maintain consistent supplies. Storing energy is not easy, which is why tidal power is appealing. Every 12 hours and 25

minutes, without fail, the tides go up and down, and it is this reliable tidal movement – and how fast the water moves between tidal zones – that makes all the difference.

Jennifer highlights the abundance of water sources on our planet. “Energy is contained in moving water, either from waves, from steady currents of water in tidal zones, in rivers or ocean currents offshore.” There is global demand for energy, and while people live in varying environments and climates, marine energy could be used all over the world. Jennifer explains, “Moving water is available in many high-density locations (such as in rivers or tidal channels near big cities) and also remote locations (where island or Indigenous communities are not reliably connected to an electric grid).”

WHAT IS AN OSCILLATING HYDROFOIL?

The task for engineers like Jennifer is to find an efficient way to capture the movement of water. She explains, “Previous attempts operate on the same basic principles as wind turbines, but the problem is that rotational devices spin very fast, which can cause seaweed or fishing lines to get tangled in them and could have adverse effects on wildlife”.

Instead of a spinning machine, Jennifer and her team are working on a device that is driven by a clean and constant flow of water. “This oscillating motion is slower and more similar to the flapping motions of nature, such as a fish or marine mammal propelling itself through the water,” she explains.

The hydrofoil is the part of the device that rises and falls like the end of a seesaw as water flows past it. This is similar to how an aeroplane wing uses the horizontal movement of air to generate upwards lift. The hydrofoil has a surface which it fixes at an angle (known as the angle of attack) compared to the direction the water is flowing in, so that it is pushed up towards the surface. When it reaches the top of its oscillation, the hydrofoil switches its angle of attack so the flow of water now pushes it back down again, until it reaches the bottom, switches angle of attack again and repeats the cycle.

HOW CAN COMPUTERS HELP BUILD THE PERFECT SYSTEM?

Jennifer and her engineering collaborators have built prototypes and tested them in the lab and in the sea at Cape Cod Bay, Massachusetts. She explains, “Our experiments show the device can work for a wide range of tidal flow speeds in both directions.” However, a lot of the engineers’ work was done without needing to build anything at all.

Computers are vital because the physics equations that describe the motion of fluids like water are complicated and are usually impossible to solve by hand. Instead, the engineers build the equations into a simulation – essentially a computer game where the rules are the rules of physics – which the engineers then use to predict how much power they could generate from a certain design.

PROFESSOR JENNIFER FRANCK

Assistant Professor of Engineering Physics, University of Wisconsin-Madison, USA

FIELD OF RESEARCH

Aerospace and Mechanical Engineering

RESEARCH PROJECT

Developing an oscillating hydrofoil – a device to capture the energy of moving water

FUNDERS

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HOW ARE HYDROFOILS LIKE GEESE?

Have you ever wondered why some birds, such as geese, fly in a V-formation? They do this because the flapping of the front bird’s wing leaves a trail of little whirlpools behind it in the air. If the bird behind is positioned just right, it can pick up some extra lift from these whirlpools, thereby saving energy. Jennifer’s team has discovered that oscillating hydrofoils can work together in a similar way. By positioning one behind the other, the whirlpools created by the first one help to power the second.

Each little discovery like this gets us a little closer to that dream of clean, reliable energy from the oceans, and with the climate crisis as urgent as ever, it cannot come soon enough.

ABOUT MECHANICAL ENGINEERING

If you have ever looked at a machine and wondered "how does it work?", you know what excites mechanical engineers. From ships, planes and trains to human organs, animals, and robots, machines encompass literally anything that moves, and engineers are the people that design, build, test and maintain those machines. Engineers use physics to guide them but are never content with just theory. Instead, their goal is to see an idea through to a final working product.

WHY DO WE NEED MECHANICAL ENGINEERS?

Mechanical engineers keep our world moving! Their problem solving is behind the transport we use to get around, the energy and industries we rely on for food and materials, and many medical devices.

WHERE DOES AEROSPACE FIT IN?

Jennifer works in a physics engineering department, but she very much sees herself as a researcher in aerospace and mechanical engineering. She explains, "I consider aerospace a sub-set of mechanical engineering, as there is much overlap and collaboration between these disciplines in terms of university degrees and the jobs you obtain post-graduation."

WHAT FACES THE NEXT GENERATION OF MECHANICAL ENGINEERS?

Climate change is the pressing issue of our time, and mechanical – and aerospace – engineers will play a crucial role in finding solutions. This could be by re-designing machines that rely on fossil fuels to work using electricity (such as cars), so we are ready for a future without coal, oil and gas. Alternatively, it might mean working on smarter ways to heat and cool our homes so that they use less energy. Mechanical engineers will also be required to work on ways to capture carbon from the atmosphere, technology to store energy and – like Jennifer – machines for generating energy sustainably.

PATHWAY FROM SCHOOL TO MECHANICAL ENGINEERING

- The first step to becoming a mechanical engineer is usually an undergraduate degree, in which you will learn a mixture of physics, mathematics and computer science.
- Jennifer says, "It's okay if you're not an expert in all three of these subjects! I did not do very well in high school physics, but I really loved computer science and I did well in mathematics."
- It is also possible to enter mechanical engineering through apprenticeships and college courses.

EXPLORE CAREERS IN MECHANICAL ENGINEERING

- Take this online quiz to see if mechanical engineering is your thing, or if another kind of engineering might be more your ticket: **mtfy.org.uk**
- Most engineers work in companies or government agencies. To get an idea of the wide range of job options, go to the Institution of Mechanical Engineers website **www.imeche.org/careers-education/careers-information/what-is-mechanical-engineering/where-do-mechanical-engineers-work**
- Visit 'She's an Engineer' to learn about inspiring women in engineering and what they do in their jobs: **www.wes.org.uk/content/shes-engineer-1**

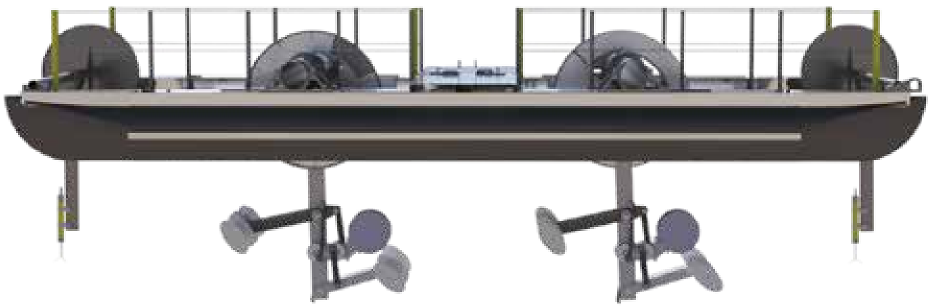
JENNIFER'S TOP TIPS

01 Work hard and keep your options open!

02 Don't let one bad grade, one person's opinion or one bad experience turn you away from a field, especially one as wide reaching as engineering.

03 Don't be put off by old stereotypes. I personally look forward to seeing more young women in the aerospace and mechanical engineering fields. Women are natural problem solvers, and we need equitable representation in the field in order to solve the hard problems that lie ahead.

Jennifer with students and engineers at a test site for the oscillating foil prototype in Cape Cod, Massachusetts, USA. (Credit: Leading Edge)



A computer aided design (CAD) of the oscillating foil prototype: a floating pontoon vessel with two pairs of oscillating hydrofoils submerged underwater. Each pair of hydrofoils is connected to a generator to convert the captured mechanical power into electricity. (Credit: Leading Edge)

HOW DID JENNIFER BECOME A MECHANICAL AND AEROSPACE ENGINEER?

WHAT WERE YOUR INTERESTS WHEN YOU WERE GROWING UP?

I had a lot of interests, but I was primarily into sports, competing almost year-round in gymnastics and track and field. Looking back, I displayed engineering tendencies unintentionally – I was always dissecting a difficult skill in gymnastics, or hurdle or jump on the track, trying to figure out the mechanism to make it higher, faster, better. Diagnosing a problem and coming up with a more effective and efficient solution is exactly what engineers do every day.

WHAT INSPIRED YOU TO BECOME AN ENGINEER?

Thanks to my father, I was exposed to computers at an earlier age than most of my peers, and I was easily fascinated by them. I taught myself some very basic programming languages and took computer science in high school (I was the only female in the class). I also did well in math, and many people hinted to me that engineering may be a good idea, although I didn't have a firm understanding of what the engineering field was.

When I entered my engineering programme at university, it took me a while to fully understand what engineers do and the numerous ways they contribute to society. Now, I tell aspiring engineering students that engineering is about problem-solving. You learn the tools, the mathematics, the physical concepts and the computer skills to design and build new and improved technology. It doesn't sound very specific, but I think this is because engineering is all around us!

WHAT LED YOU TO SPECIALISING IN MARINE ENERGY?

A pivotal moment for me was the decision to pursue a PhD and attend graduate school. I attribute this to a professor I met during my junior year who became a great mentor and launched me on a path of research and computational fluid dynamics, which is what I still work on today.

WHAT ATTRIBUTES HAVE MADE YOU SUCCESSFUL AS AN ENGINEER?

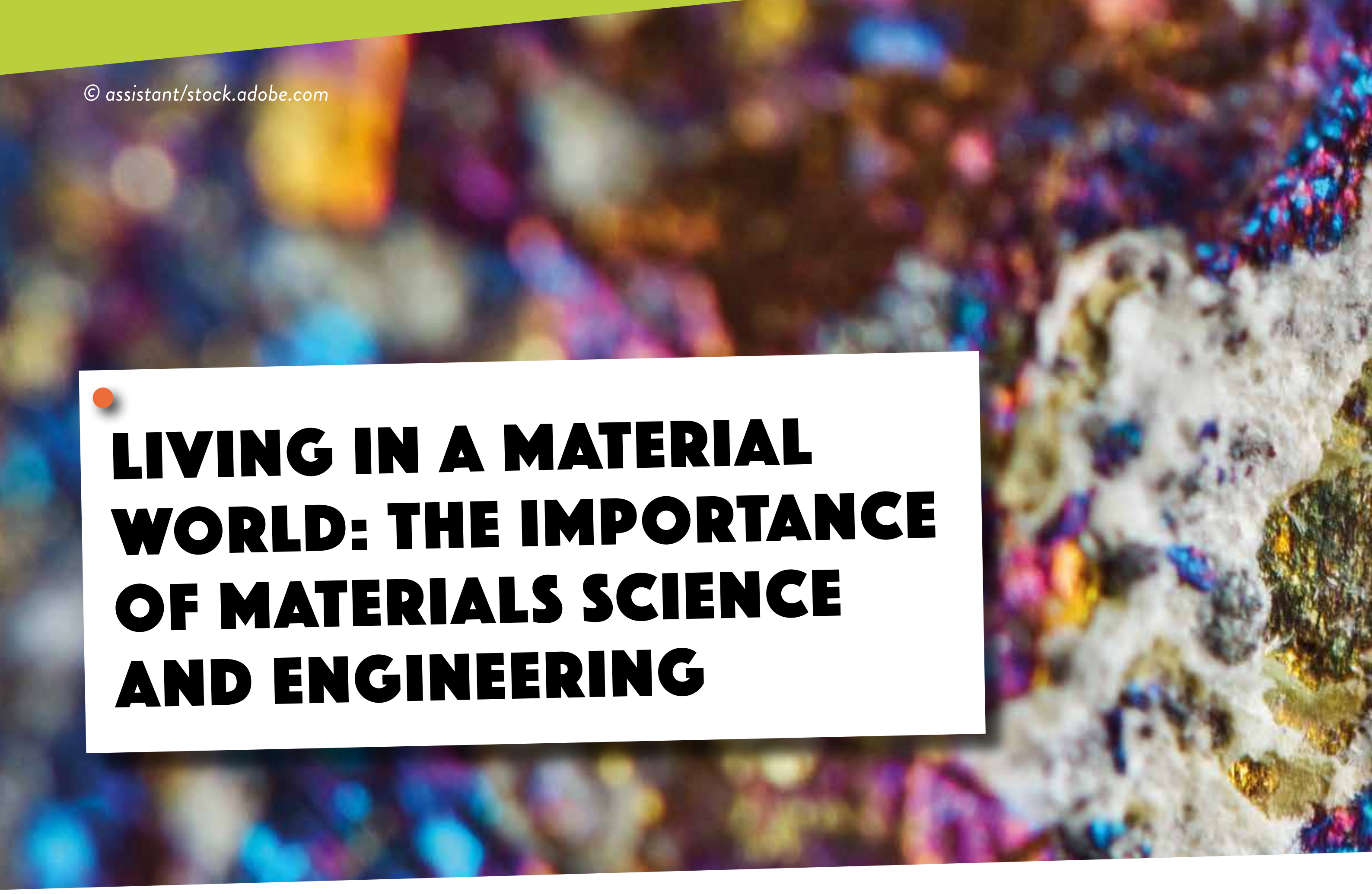
One of the most important attributes is to remain persistent and positive. When you work on challenging problems, you don't always have success, or success is small and incremental, so it can be difficult to keep going. What has helped me is having amazing colleagues and a network of people that I have met through my career.

HOW DO YOU SWITCH OFF FROM YOUR WORK?

I am fortunate to have a family – a husband and three daughters – to come home to every day after work, giving me a natural way to unplug and decompress at the end of each day. I look forward to setting my work aside and spending time with my family each evening and on weekends.

WHAT ARE YOUR PROUDEST CAREER ACHIEVEMENTS SO FAR?

As a professor, I am most proud of the students I have mentored and taught. That is the best part of my job since my impact goes beyond my research and engineering to influence and train another generation of engineers!



LIVING IN A MATERIAL WORLD: THE IMPORTANCE OF MATERIALS SCIENCE AND ENGINEERING

WHAT IS MATERIALS SCIENCE AND ENGINEERING?

Making things is a very human trait, and one that has been crucial in building the world around us. Materials Science and Engineering (MSE) is the field that deals with the science of making, characterising and testing all types of materials. "MSE has one fundamental tenet at its very centre: the relationship between the structure of a material and its properties," says Dr Ilija Rašović from the University of Birmingham, UK. "This covers anything you make things out of and is true across a huge range of scales, from the atomic level through to civil engineering structures."

Most materials we use can be categorised into one of three categories – metals, ceramics or polymers. "However, many materials nowadays are composites, which may comprise more than one of these," says Dr Fiona Hatton from Loughborough University, UK. "And, as research advances, we are making new materials that might not fall into these traditional categories, such as graphene."

While making materials is an important aspect of MSE, it is only useful if it is accompanied by testing them to understand their properties. "MSE helps us understand how materials behave and how to control their behaviours," says Dr Chris Hamlett, Discover Materials National Outreach Officer. "This allows the development of new materials and also provides new ways in which we can use existing materials."

PROPERTIES AND PROCESSES

Materials scientists and engineers are interested in properties that affect how a material behaves and, therefore, how it can be used. "The mechanical properties of a material describe how it behaves in response to a force," explains Chris. "Testing these properties answers questions about the material. How bendy is it? How easily is it stretched? How hard is it?" To discover these properties, scientists 'test materials to destruction' – they deliberately break the material and record the force needed to achieve this. A material's chemical properties are equally important. "Its chemical properties define how it reacts to different environments, which is important when thinking about processes such as corrosion," says Chris.

The construction of a material can also significantly affect its properties. "If you manufacture something with a new processing method, it may have a different grain structure and therefore different mechanical properties, which can affect whether or not you can use it for the same application," says Fiona. This highlights the intersection between different 'traditional' fields of science in MSE. Expertise in physics and chemistry is needed to explore material properties, while engineering skills are needed to manufacture and test materials.

STRUCTURE AND SCALE

MSE considers how materials behave at every scale. Materials scientists and engineers are interested in the microstructure of materials, as the arrangement of individual atoms and molecules will have a huge influence on the macroscale properties of materials, such as their ability to conduct electricity or heat. "The microstructure of a material affects its physical behaviour," explains Chris. "Careful control of a material's microstructure can lead to some amazing behaviours." One example is shape memory alloys – metals that can be bent, then returned to their original shape by applying heat.

"Once you understand the fundamentals of how structure affects properties, you open up a huge playground in which you, as the materials scientist or engineer, can explore exciting new possibilities for the manipulation of materials to achieve certain ends," says Ilija.

APPLICATIONS AND ADVANCES

To ensure it has direct value to society, MSE research must always consider the potential applications of different materials, which often involves knowledge of wider

APPLICATIONS OF MSE IN THE MODERN WORLD

- If concrete was a country, it would be the world's third largest emitter of carbon dioxide! Developing new building materials and new methods of concrete production are therefore key tasks in reducing global greenhouse gas emissions. This is why materials scientists and engineers at the University of Manchester, UK, have invented concretene, concrete containing graphene, which is significantly stronger than standard concrete, meaning less needs to be used in construction.

- If we want to colonise space, how will we construct homes on the Moon or Mars? Materials scientists and engineers at the European Space Agency think they have found the answer – from concrete made by mixing moondust with astronauts' urine!

- Bamboo is incredible – strong, lightweight, flexible, quick-growing, biodegradable, antibacterial... These are just some of its many useful properties. Bamboo has been used in construction for centuries and is still used to build scaffolding in Hong Kong today. Materials scientists and engineers have been exploring uses for this wonder-material, and you will now find utensils, furniture and flooring made from bamboo, as well as clothes and cricket bats.

- Keeping surfaces and equipment sterile in hospitals is a huge challenge. This is why materials scientists and engineers at Loughborough University, UK, are developing anti-biofilm coatings – materials that are resistant to bacteria. This involves not only controlling the surface chemistry of polymers, but also developing polymers from renewable resources such as plant oils instead of petroleum.

TALK LIKE A MATERIALS SCIENTIST AND ENGINEER

ALLOY — a metallic material made of two or more elements

CERAMIC — a material made by heating inorganic non-metallic components, such as clays

COMPOSITE – a material made from two materials with different physical and chemical properties

POLYMER – a material containing large molecules composed of repeating smaller units

fields. "It is of fundamental importance that a materials scientist or engineer understands the needs of the application area in which they are working," says Ilija. If you are creating materials for medical applications, you will need some knowledge of biology, while if you are designing sports equipment, you will need to understand the specific needs of the participants.

While scientific understanding is key to MSE, it is a field defined by innovation and creative thinking. "Materials scientists and engineers are increasingly seeking inspiration from exquisite structures found in nature that have evolved over the course of billions of years," says Ilija. "Additionally, as with every area of our modern world, computers have revolutionised MSE." Computational MSE is now a huge branch of the field, involving modelling material behaviour and using machine learning to accelerate materials discovery.

As innovation continues and methods for materials research and development become ever-more powerful, the future is looking bright for the field of MSE. "Everything around us is made of something," says Ilija. "At some point, a materials scientist or engineer was involved in developing or characterising the material." How could you contribute to this exciting field?

EXPLORE CAREERS IN MATERIALS SCIENCE AND ENGINEERING

- As materials form the basis of almost everything we use in life, a degree in MSE opens a wide range of career opportunities, from 'traditional' manufacturing jobs, to designing and developing new materials for a variety of applications.

- Discover Materials has collated a wealth of resources for those exploring careers in MSE. There is careers advice, videos exploring potential MSE pathways, and examples of the career paths that graduates have followed: **www.discovermaterials.co.uk/resource/careers-in-materials-science-and-engineering**

- The Institute of Materials, Minerals and Mining provides resources for students and teachers, including information about careers in the field: **www.iom3.org/careers-learning/schools-outreach.html**

- The Henry Royce Institute runs materials-related events and outreach activities across the UK: **www.royce.ac.uk/outreach**

PATHWAY FROM SCHOOL TO MATERIALS SCIENCE AND ENGINEERING

- At school, maths, chemistry and physics will be useful subjects for studying MSE at university.

- At university, study materials science and engineering, or a related degree such as metallurgy, aerospace engineering, biomaterials engineering or chemical and materials engineering.

- You can also enter the field of MSE from a non-science background. Studying design and technology, art or fashion could lead to a career in MSE.

A scanning electron microscope image of cuttlefish bone. The structure gives the bones great stiffness yet light weight and inspired the design for the corrugated cardboard used to make postal boxes © Mark Coleman, Discover Materials

MEET SOME MATERIALS SCIENTISTS AND ENGINEERS

DINA FOUAD

PhD Student, EPSRC CDT in Topological Design, School of Metallurgy and Materials, University of Birmingham, UK

Post-16 subjects studied: *Maths, Physics, Business Administration*

I'm passionate about the discoveries that take place in materials science. I call myself a 'materials astronaut' because I feel like I am exploring the planet of materials, and I love it! The discovery or improvement of materials has the power to change our lives and have a real positive impact on the world.

Everything in life is made of a material. Understanding materials is key to understanding the world. It is integrated in design, manufacturing, research, innovation, development – everything. Working in MSE means there's the possibility of being the inventor of the next big thing!

My current research involves examining the microstructure of 3D-printed bone-like structures for medical implants, to swap worn-out joints with titanium replacements. This has been a real highlight of my MSE career so far.

In the future, I would love to teach materials science and explore more of it. My astronaut journey on the planet of materials continues.

Titanium is my favourite material. It's strong, tough and relatively light compared to steel – a tough cookie, like me!

"I CALL MYSELF A 'MATERIALS ASTRONAUT' BECAUSE I FEEL LIKE I AM EXPLORING THE PLANET OF MATERIALS, AND I LOVE IT!"

EBRIMA SALLAH

PhD Student, Materials Science and Engineering, Swansea University, UK

Post-16 subjects studied: *Maths, Biology, Chemistry, Sociology*

I came across my industry-based MSE doctoral programme while looking for opportunities for further professional development. It enthused my interest in the science of materials and engineering and is allowing me to gain both academic and practical industrial experience.

MSE is key to solving the world's major problems. It will help us get cleaner forms of energy, discover how to effectively use waste to work towards a circular economy, and find better ways to source materials and manufacture products with lower carbon emissions. The field of MSE has good opportunities for developing lifelong skills that can be applied to address our planet's biggest issues.

My current research involves finding efficient experimental methods for industry to conduct failure analysis and monitor the health of a highly heat-resistant ceramic material. These materials are heavily relied upon by metal-making industries to contain molten metal. It's important that they're not only safe from failure, but also that they maintain the temperature of molten metal to save energy.

A highlight of my career was the publication in a high-impact scientific journal of a failure analysis that I hope can be adopted by industries to save them time and money. I've had opportunities to develop non-destructive test methods for failure analysis, using sound waves and lasers.

I hope to make STEM more accessible for all by taking part in outreach programmes throughout my career. I have designed and delivered STEM-based workshops related to my research at local schools, and I enjoy running activities during science festivals.

Ceramics are my favourite type of material. They have a wide range of applications, from electronics (resistors) to military defences (armoured vests) to aircraft (jet engines). And, of course, they are highly useful in the kitchen (plates and mugs) and bathroom (tiles and bathtubs).

JESSICA TJANDRA

PhD Student, Department of Materials, Imperial College London, UK

Post-16 subjects studied: *Physics, Chemistry, Maths, Economics*

I chose MSE through a process of elimination – I knew I wanted to study engineering but wasn't sure which type. I loved physics, chemistry and mathematics equally, but most engineering courses only focus on two out of the three. MSE is truly a mix of all three!

Materials are literally everywhere. Believe it or not, all engineering branches rely on MSE. Electronic devices are only what they are today with the development of ever-smaller transistors, modern buildings rely on composites developed through MSE, and aeroplanes use engineering alloys and ceramic coatings to fly efficiently.

My current research looks at the corrosion behaviour of 3D-printed titanium alloys for bone implants. Once these implants are in the body, they're exposed to mechanical and chemical stresses through the weight of the body, friction and wear at the joints, and the chemical and thermal conditions of the body. I mimic these conditions in the lab to see how implants behave and degrade over time.

I love sharing how cool MSE is with people! I have been involved in many outreach activities, working with children as young as five through to adults. Getting young people excited about MSE, and STEM in general, has been really rewarding. I feel I learn at least as much as the target audience through these activities.

As a final year undergraduate, I conducted a research project with Rolls-Royce. I got to see compressor and turbine blades that are used in Rolls-Royce engines, meet experts in the field of MSE, and see how the results of my research directly impacted the development of new engines.

Titanium is a great material. It's much lighter than steel but just as strong. With these properties, it gets used a lot in the aerospace industry, but also makes a great material for replacing our bones and joints. It is largely resistant to corrosion and, unlike most metals, doesn't conduct much heat.

DR LEAH-NANI ALCONCEL

Lecturer, School of Metallurgy and Materials, University of Birmingham, UK

Post-16 subjects studied: *Chemistry, Physics, Maths*

Neither my undergraduate degree nor PhD were in MSE, but in chemical physics. However, MSE has been a key part of my postdoctoral career. As Product Assurance Manager for a magnetometer used on spacecraft, I was responsible for assessing the material and mechanical properties of every component of the instrument. It was time-consuming work, but fascinating.

MSE underpins so many other fields. For instance, it's a crucial part of spacecraft engineering. Measuring and understanding material performance under the extreme conditions found in space determines whether or not a spacecraft will survive its mission.

I'm interested in space-based dataset management and archiving, space payload instrument development and inclusive STEM teaching. I enjoy building and testing space hardware with my students.

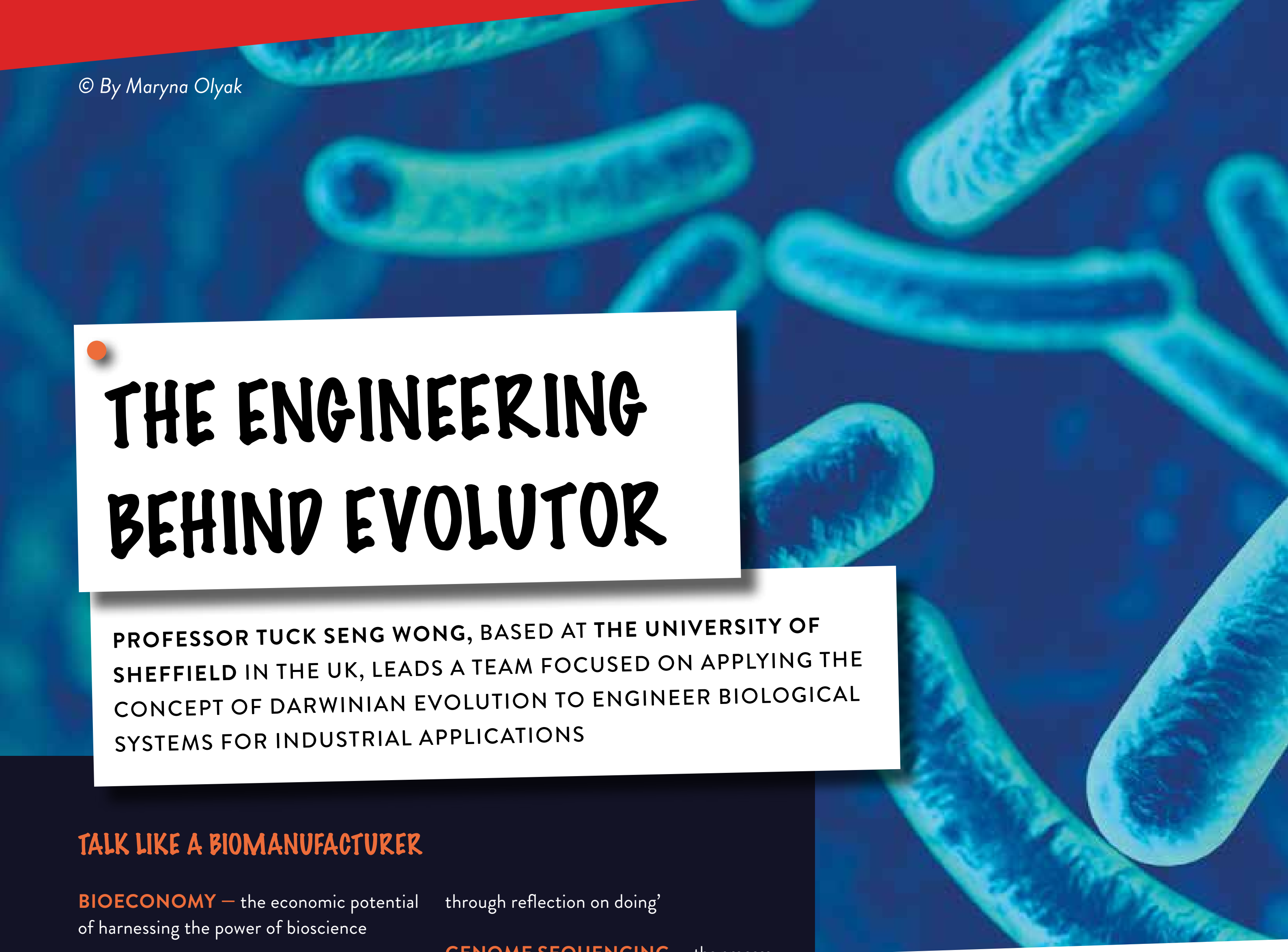
The coolest thing I've done in my career is drive the Cassini spacecraft around Saturn! More directly related to MSE, I am proud to have won a Royal Academy of Engineering Ingenious Award, which allowed me to work with an artist to develop photography workshops to inspire students to study MSE.

In the future, I would love to build our space engineering capabilities at the University of Birmingham to the point where we can test new materials in space through regular satellite launches.

I'm a big fan of aluminium. Although the process of extracting it is expensive and unpleasant, it's incredibly cost-effective to recycle. It's also lightweight, can easily be combined with other metals to produce space-worthy alloys and is great at shielding sensitive electronics from radiation.

DISCOVER MATERIALS

Though they work on different topics and are spread out across the UK, all the researchers in this article are part of the Discover Materials network. Discover Materials acts as a hub for students, teachers and parents to explore the world of Materials Science and Engineering. You can find resources about the applications of MSE in our daily lives, activities to do at home or in the classroom, and information about careers in the field. The researchers featured on this page are Discover Materials ambassadors, who deliver workshops in schools and offer support for teachers. To learn more, visit: **www.discovermaterials.co.uk**



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THE ENGINEERING BEHIND EVOLUTOR

PROFESSOR TUCK SENG WONG, BASED AT **THE UNIVERSITY OF SHEFFIELD** IN THE UK, LEADS A TEAM FOCUSED ON APPLYING THE CONCEPT OF DARWINIAN EVOLUTION TO ENGINEER BIOLOGICAL SYSTEMS FOR INDUSTRIAL APPLICATIONS

TALK LIKE A BIOMANUFACTURER

BIOECONOMY — the economic potential of harnessing the power of bioscience

ENZYMES — the proteins responsible for catalysing all chemical reactions in cells

EVOLUTION — the change in the characteristics of a species over several generations, which relies on the process of natural selection

EXPERIENTIAL LEARNING — the process of learning through experience, more narrowly defined as 'learning through reflection on doing'

GENOME SEQUENCING — the process of determining the entirety, or nearly the entirety, of the DNA sequence of an organism's genome

NATURAL SELECTION — the process through which populations of living organisms change and adapt

SURVIVAL OF THE FITTEST — a phrase that originated from Darwinian evolutionary theory as a way of describing the mechanism of natural selection

Charles Darwin revolutionised our understanding of life on Earth when he presented his concept of natural selection in his ground-breaking book *On the Origin of Species* in 1859. Natural selection is the process by which living organisms change and adapt and is a key mechanism of evolution. Organisms that are better adapted to their environment are more likely to survive, which means the genes that enabled their survival are more likely to be passed on.

We have come a long way since Darwin published his concepts, and engineers and scientists have borrowed the concept of 'survival of the fittest' and applied it to engineering biological systems for industrial applications. Professor Tuck Seng Wong, a chemical engineer and biomanufacturer based at the University of Sheffield, explains this process of mutation and selection with this very useful analogy: "Mercedes has dominated the Formula 1 race by winning the constructors' titles (that celebrates the car designers rather than the drivers) consecutively since 2014. Among the F1 constructors (e.g., Ferrari, Williams, McLaren, Red Bull, etc., which are examples of variation), Mercedes has proven to be the best chassis and engine manufacturer in the F1 race, and so is the 'chosen' winner." So, how does this relate to Tuck's work?

In our evolving world, where climate change is forcing us to look at manufacturing and technology from a new perspective, Tuck and his team believe that applying this Darwinian concept to biomanufacturing will help provide the solutions we need for a sustainable future. Tuck explains, "We deliberately introduce mutations into a biological system (e.g., a gene encoding an enzyme) and apply artificial selection to perpetuate a desirable trait (e.g., an enzyme with higher activity) in order to expedite the process of evolution."

EVOLUTOR

By evolving microbes, the team can optimise natural resources. Tuck explains, "Bacteria and yeast can be adapted to turn waste products into food ingredients, biodegradable plastics, biofuels and other valuable resources." Microbes need to be evolved and adapted to do these specific jobs, and Tuck and his team have developed Evolutor to do just that. The Evolutor technology enables them to evolve microbes with specific properties and, importantly, with accuracy and predictability.

The elements of Evolutor which make such precision possible have been developed through experiential learning – learning by doing. The team in Sheffield has over 40

years of accumulated research experience in applying an evolutionary approach to engineering biology. "Our advances are the manifestation of our experience (both good and bad) in laboratory evolution," says Tuck. "The intelligent control of Evolutor allows us to automate the laborious workflow of evolution, bypass human intervention, reduce human error, lower the risk of contamination and achieve a predictable and positive outcome of laboratory evolution."

GENOME SEQUENCING

Genome sequencing allows the team to 'read' the genetic alphabets in a genome. "By comparing a DNA sequence against a reference, engineers or scientists can quickly identify the genetic variations that are responsible for a trait," explains Tuck. "For example, if we isolate a baker yeast variant that produces more biofuel, such as isobutanol, we will be able to understand the genetic basis of this improvement in productivity through sequencing the genome of this yeast variant. Mutations responsible for trait improvement are commonly referred to as beneficial mutations."

HARDWARE DESIGN

The team believes that, in engineering, simplicity is often the best solution, so it has ensured its hardware and software are not complicated. They are designed to be goal-oriented, in that they do what they are supposed to do, and user-focused, so they can be used by target users. These product design principles have enabled the team to build a 'fit-for-purpose' device that enables its users to automate laboratory evolution to save time and resources. The data collected by the Evolutor provide a more predictable evolution outcome – microbes can be optimised as intended and without any lengthy processes or unexpected errors.

EVOLVING PROPERTIES

Evolutor has been built in response to the 'Bio Revolution', the biological science innovations that are able to transform economies, societies and our lives. These innovations are designed to help us tackle the global challenges we face, from climate change to pandemics. "Evolutor is a clever device, which allows us to manipulate and control the conditions of microbial growth. Through increasing or reducing the temperature of the microbial cultivation chamber, we can select microbial sub-population that tolerates high temperature (evolving for thermotolerance) or low temperature (evolving for cold adaptation)," explains Tuck. "Depending on how we design the experiment or operate the Evolutor, we can evolve a wide range of microbial properties such as carbon utilisation (microbes need food to grow and to manufacture a product), pH tolerance, inhibitor tolerance, product tolerance and productivity."

APPLICATIONS IN MANUFACTURING

Evolutor's microbe optimisation capabilities can be widely applied across many biotech industries. Due to the team's evolution-based approach, it is able to optimise any microbe, regardless of the availability or confidentiality of genetic information. "The next-level microbe development capabilities of the Evolutor technology are especially relevant for bio-manufacturers in food and drink, pharmaceuticals and biologics, chemicals, agri-tech, biofuels, nutritional ingredients and microbiome health, materials, and flavours and fragrances," says Tuck. The breadth of application is huge; the potential impacts bigger still.

PROFESSOR TUCK SENG WONG

Department of Chemical and Biological Engineering, University of Sheffield, UK

FIELD OF RESEARCH

Biomanufacturing

RESEARCH PROJECT

Applying the concept of Darwinian evolution to engineer biological systems for industrial applications

FUNDERS

Royal Academy of Engineering, Research England, Innovate UK, Biotechnology and Biological Sciences Research Council (BBSRC), The University of Sheffield

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TEAM SUCCESS

Tuck is keen to emphasise the importance that teamwork has played in the development of Evolutor. For him, it would not have been possible to develop Evolutor without the input of every team member who brings their own experience, skill, enthusiasm, commitment, persistence and hard work to the project.

THE NEXT STEPS

Tuck and his team now want to understand biological blueprints through the lens of evolution. "Biology is complex. Microbial cell factories can manufacture fascinating molecules (e.g., bioplastic and antibiotics). How these factories are designed and constructed is still a puzzle to engineers and scientists," explains Tuck. "Through laboratory evolution, we hope to develop a better understanding of the genetic makeup of a microbe, the gene function and how the genes are regulated."

ABOUT BIOMANUFACTURING

Biomanufacturing is a type of manufacturing or biotechnology that makes use of biological systems to produce a range of applications for use across various industries. Scientists within the field can come from several different arenas, including chemical engineering, biochemical engineering, protein engineering, engineering biology, microbiology, molecular biology and genetics.

OPPORTUNITIES

Tuck and his team's research helps the UK make the transition into a circular bioeconomy and build a sustainable future. "We turn sustainable and economical carbon feedstock into bio-products," says Tuck. "Ultimately, this brings direct benefits to society."

"Mother Nature is the best engineer!" explains Tuck. "She has evolved some of the most interesting solutions for us to exploit (e.g., microbes that can capture and utilise CO_2, microbes that produce bioplastics, microbes that make hydrogen, etc.). These are the opportunities for our next generation of biomanufacturers!"

PATHWAY FROM SCHOOL TO BIOMANUFACTURING

Tuck recommends students study mathematics, physics, chemistry and biology to enter the field of biotechnology and biomanufacturing.

You will usually need a degree in a relevant scientific subject such as biotechnology, bioscience, microbiology, biochemistry or chemical engineering.

www.nationalcareers.service.gov.uk/job-profiles/biotechnologist

EXPLORE CAREERS IN BIOMANUFACTURING

- The Department of Chemical and Biological Engineering, where Tuck and his team are based, offers public outreach to teach people about this field, and Tuck often delivers talks to sixth form colleges and international schools. Find out more: **www.sheffield.ac.uk/schools**
- Built with Biology has some great information about the mind-blowing innovations that are happening across the bio-industry: **www.builtwithbiology.com/read-biology**
- There are a range of science magazines and professional engineering institution webpages that could prove useful to those interested in pursuing a career in biomanufacturing. The Chemical Engineer (**www.thechemicalengineer.com**), IChemE (**www.icheme.org/education**), Royal Academy of Engineering (**www.raeng.org.uk/education/this-is-engineering**) and The Scientist (**www.the-scientist.com**) are notable examples.
- According to Prospects, the starting salary for graduates generally is between £19,000 and £24,000, although more experienced biotechnologists can earn between £25,000 and £50,000: **www.prospects.ac.uk/job-profiles/biotechnologist#salary**

MEET PROFESSOR TUCK SENG WONG

I wanted to be a medical doctor when I was young. Unfortunately, my parents couldn't afford my tuition fee in a medical school. I started my engineering education after winning a full scholarship, offered by the Department of Chemical Engineering at the National University of Singapore. It turned out that engineering suits me!

I have been greatly inspired by Nobel Laureate Professor Frances H. Arnold (Nobel Prize in Chemistry 2018). I was awarded a Summer Undergraduate Research Fellowship by the California Institute of Technology when I was still an undergraduate student studying chemical engineering. The fellowship allowed me to spend time in Arnold's lab, and my passion in laboratory evolution was kindled by this experience.

I owe my success to not giving up! I am always curious and want to do more and better.

A eureka moment in my career was when I received a Proof of Concept fund from the Royal Academy of Engineering for my Evolutor idea on my second attempt (I failed in my first attempt). Without this fund, it would not have been possible for us to establish Evolutor Ltd. A Proof of Concept fund is by invitation only. The scheme is only open to academics holding fellowships awarded by the Royal Academy of Engineering. I held two fellowships from the Royal Academy of Engineering – an Industrial Fellowship in 2016 and The Leverhulme Trust Senior Research Fellowship in 2019.

My top three proudest achievements are: establishing Evolutor Ltd, publishing my protein engineering textbook and winning six awards for Excellence in Learning & Teaching.

My ambitions for the future: (1) continue to create impact through the science we do in Sheffield, (2) help South-East Asian countries (where I come from) to develop their Research and Development (R&D). I am currently a Visiting Professor at BIOTEC in Thailand and an Adjunct Professor at the Bandung Institute of Technology in Indonesia, (3) coach young researchers from Black, Asian and minority ethnic (BAME) backgrounds.

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MEET THE TEAM

JOE PRICE

Joe describes himself as "the interface between the team's research and the commercial world".

"I've always loved biology and nature. This passion inspired me to study zoology and introduced me to the exciting world of bio-industry.

My career, so far, has been driven by wanting to disrupt old-fashioned systems and industries. My biggest eureka moment was when I first discovered how our bio-factories can change the world.

Speaking to businesses across the globe and learning about everything they are doing to solve some of our world's biggest problems have been highlights for me.

My ambition is to lead Evolutor Ltd. to be the leading developer of biological factories in the UK and, one day, beyond!"

A DAY IN THE LAB IN THREE WORDS:
Exciting. Thought-provoking. Busy!

JOE'S TOP TIP: Start to think now about what your interests are, how you can pursue them and how you can make a positive impact in the world.

DR IWONA SMACZYNSKA-DE ROOIJ

Iwona uses almost thirty years of expertise in physiology, molecular biology, and genetics of common and pathogenic yeasts to construct new strains that can withstand a variety of growing conditions and produce substances useful in medicine, food and chemical industries.

"The person who inspired me to become a scientist was Professor Tomasz Umiński, who later became my zoology lecturer. I first met him when I was eleven years old. He told me then that there is nothing more beautiful than the variety and complexity of life, and that if I decided to study its secrets in the future, it might not be an easy road, but it would certainly be a rewarding one. Throughout my scientific career, I have always worked with yeasts, trying to unlock the secrets of their life and function. Now, it is time for me to make changes in them and alter their functioning myself."

A DAY IN THE LAB IN THREE WORDS:
Genetic-manipulation. Cultivation. Research.

IWONA'S TOP TIPS: Do not to be afraid to challenge yourself. Do not give up your dreams.

ASSISTANT PROFESSOR KANG LAN TEE

Kang Lan co-creates ideas with Tuck and applies over twenty-years' engineering biology experience to the research.

"I find the idea of applying scientific knowledge to solve real life challenges very exciting and the outcome very rewarding.

I always enjoyed STEM subjects in school. I liked their logic and how they help us understand the things around us. From everyday events like how the colours in rainbow are created and why fish do not freeze in winter, to more complex systems like how the age-old concept of evolution can improve industrial biomanufacturing.

Developing Evolutor, I enjoyed working with this great team. The incorporation of Evolutor Ltd. to enable more people to benefit from our technology is also a highlight."

A DAY IN THE LAB IN THREE WORDS:
Design. Analyse. Solve.

KANG LAN'S TOP TIP:
A good plan is half the battle won, but the unknown is worth exploring.

MATTHEW HUTCHINSON

Matthew is a research scientist and manager providing laboratory support to the group.

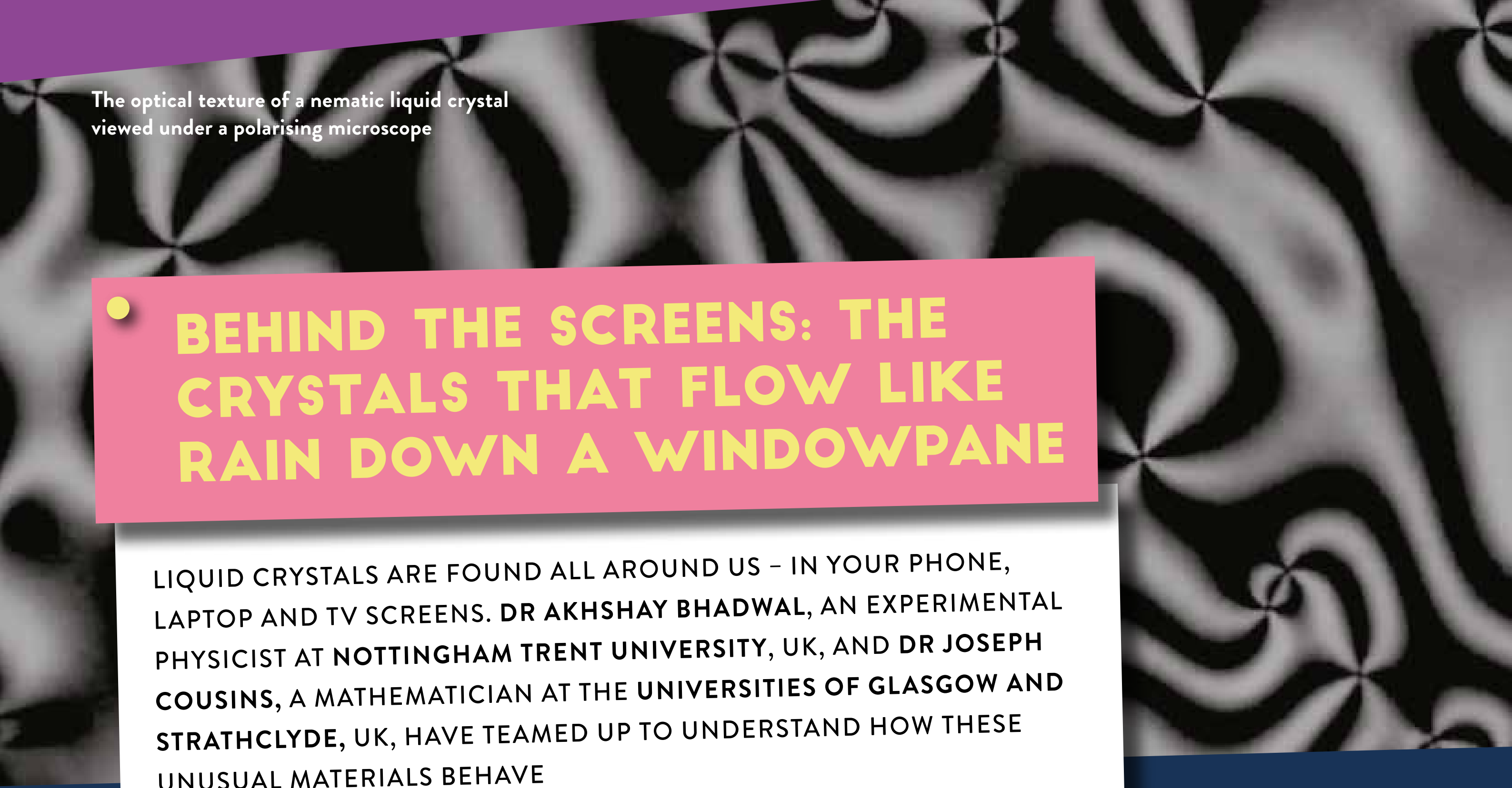
"Growing up, I always had an interest in science, and I've been lucky enough to follow my interest into my career.

I've worked in multiple labs in different research areas, but all of them have helped me grow as a scientist and develop various skills I use in my research today. My eureka moment was when I learned it's okay to ask questions!

It's always interesting working on the translation of scientific principle into something practical – with Evolutor, it's exciting because it's so novel and so close to commercial use. I want to be able to see something in the real world and be able to say, I helped make it happen."

A DAY IN THE LAB IN THREE WORDS:
Plan. Experiment. Analyse.

MATTHEW'S TOP TIP:
Be adaptable and willing to learn new things. You never know how exactly your career will develop and what opportunities may become available.



The optical texture of a nematic liquid crystal viewed under a polarising microscope

BEHIND THE SCREENS: THE CRYSTALS THAT FLOW LIKE RAIN DOWN A WINDOWPANE

LIQUID CRYSTALS ARE FOUND ALL AROUND US – IN YOUR PHONE, LAPTOP AND TV SCREENS. **DR AKHSHAY BHADWAL**, AN EXPERIMENTAL PHYSICIST AT **NOTTINGHAM TRENT UNIVERSITY**, UK, AND **DR JOSEPH COUSINS**, A MATHEMATICIAN AT THE **UNIVERSITIES OF GLASGOW AND STRATHCLYDE**, UK, HAVE TEAMED UP TO UNDERSTAND HOW THESE UNUSUAL MATERIALS BEHAVE

TALK LIKE A SOFT MATTER PHYSICIST

CRYSTAL – a solid material with a high degree of internal ordering of its molecules

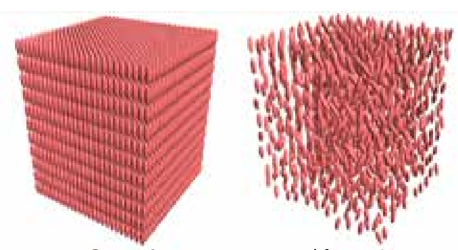
FLUID – a material that flows and changes shape when a force is applied to it, including liquids and gases

LIQUID CRYSTAL – a material that flows like a liquid but has some properties of crystals

NEMATIC – a type of liquid crystal, in which molecules tend to align with each other

POLARISATION – the orientation of a light wave, a property used in technology to control light

VISCOSITY – a measure of a fluid's internal friction, a property perceived as the fluid's 'thickness' or 'stickiness'. Viscous fluids are sticky and flow slowly while less viscous fluids are runny and flow quickly



When was the last time you looked at a computer, TV, phone or tablet? Perhaps you are reading from one now. If so, you are almost certainly using a liquid crystal display (LCD). While you may have heard the term LCD before, have you ever wondered how they function?

Dr Akhshay Bhadwal is an experimental physicist at Nottingham Trent University, and his job is to explore how LCDs function by conducting experiments with liquid crystals. Helping him to understand the results is Dr Joseph Cousins, a mathematician at the Universities of Glasgow and Strathclyde. Together, they are investigating a certain type of liquid crystal, known as a nematic.

WHAT ARE NEMATICS?

In 1888, Friedrich Reinitzer, an Austrian scientist, was experimenting with a chemical he had extracted from carrots when he found something strange. As he heated the chemical, it initially converted into a cloudy liquid. On further heating, this cloudy liquid became clear. In the cloudy liquid phase, he had accidentally discovered liquid crystals – materials that flow like liquids but have some properties of crystals.

Since then, scientists have discovered many different phases of liquid crystals. One of the most important phases is the nematic phase, which has a thread-like texture when observed under a polarised light microscope. Unlike solid materials, in which molecules are fixed in position, molecules are free to move in the nematic phase, but, on an average, point in a preferred direction that aligns with the other molecules (see diagram above). This average alignment gives nematics some properties of crystals, while the freedom molecules have to move gives them some properties of liquids.

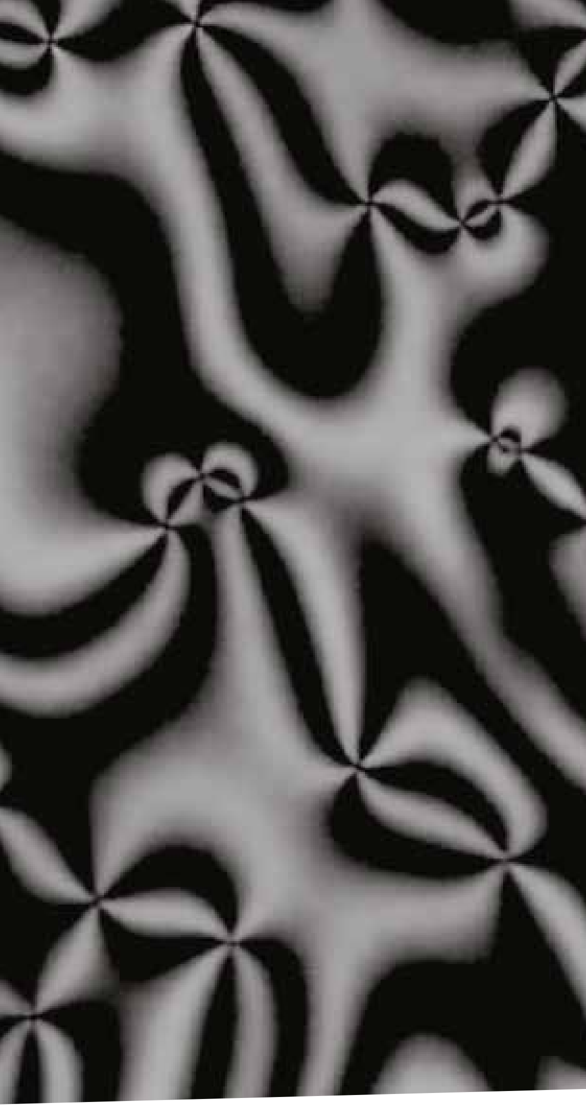
HOW CAN WE USE NEMATICS?

The orientation-dependent properties of nematics give them two special features that are useful for LCDs. Firstly, the molecular structure can change the polarisation of light. Secondly, the way the molecules align can be changed by applying a voltage across the nematic. The LCD in your phone works by controlling the voltage applied to the nematic, which alters the polarisation of the light passing through different parts of the display. This control allows the creation of an image on the screen.

As well as being used in technology, nematics are also found in nature. The cytoplasm in living cells has a nematic state and a spider's silk is nematic before it solidifies.

WHAT ARE FREE SURFACES?

Boundaries between two fluids (for example water and air) are known as free surfaces, and they are found wherever two fluids meet. "For small volumes of fluid, the shape of these free surfaces is typically determined by surface tension, which arises from the cohesion of



DR AKHSHAY BHADWAL

School of Science and Technology, Nottingham Trent University, UK

FIELD OF RESEARCH

Experimental Physics

DR JOSEPH COUSINS

Department of Mathematics and Statistics, University of Strathclyde, UK

School of Mathematics and Statistics, University of Glasgow, UK

FIELD OF RESEARCH

Applied Mathematics

RESEARCH PROJECT

Control of free-surface flow morphologies in anisotropic liquids (Grant numbers EP/T012986/1 and EP/T012501/2)

FUNDER

Engineering and Physical Sciences Research Council (EPSRC)

molecules on the free surface," explains Joseph. "For larger volumes of fluid, gravity also becomes important."

In general, surface tension acts to minimise the surface area of the free surface. Mathematically, a sphere is the shape that minimises the surface area of a fixed volume, explaining why small water droplets on a flat surface take the shape of a spherical cap. But, when enough water droplets collect to form a puddle, the effects of gravity take over, giving the puddle a flat free surface.

Akhshay and Joseph have been studying the free surfaces of nematics. Here, as well as surface tension and gravity, the orientation of the molecules also comes into play. Because applying a voltage changes the orientation of the molecules, this can be used to change the shape of the nematic free surface.

AKHSHAY'S PHYSICAL EXPERIMENTS

Akhshay has been watching how nematics flow down a sloped pane of conductive glass in thin streams called rivulets. If you look out the window on a rainy day, you can see for yourself how raindrops form rivulets when they slide down the glass. In Akhshay's experiments, he can control exactly where the rivulet forms and the speed at which it flows, and he can also apply a voltage across the glass. He then uses cameras and microscopes to measure the height of the rivulet free surface under different flow speeds and voltage conditions.

The experiments have shown that the free surface of a nematic can be controlled by the applied voltage. "When molecules align along the direction of flow, the nematic is less viscous," says Akhshay. "However, as you increase the voltage, molecules increasingly align along the electric field and the liquid becomes more viscous. As a result, the flow slows down and the height of the rivulet free surface increases."

JOSEPH'S MATHEMATICAL MODELS

While the experimental results show how nematics behave, the next step is to develop a mathematical description of what is happening. This not only helps scientists understand what is going on behind the scenes, and why, but also helps to enable the physics to be applied in technology in the future. For example, as Akhshay can control a rivulet by applying a voltage, he might want an equation to estimate how much the height of the free surface will change for a given change in voltage.

This is where Joseph comes in. He starts by considering some basic principles of physics – that the momentum and energy of a system are always conserved. "The problem is that considering every possible effect that contributes to momentum or energy is complicated," he explains. The results of Akhshay's experiments, however, help to show Joseph which are the important factors. He uses these key factors to construct mathematical models that capture the key physical effects of nematic behaviour.

COMBINING EXPERIMENTS AND MATHEMATICAL MODELS

Joseph builds mathematical models based on the key aspects of the system, then uses them to predict what will happen when Akhshay changes a variable in the physical experiment. Akhshay then conducts that experiment, and they compare their results. "We compare the measured experimental value with the value calculated from the model to check how well our theoretical model predicts the experimental outcome," explains Akhshay. "Once the models and experiments agree with each other, we can then use the model to determine other parameters which can't be found experimentally."

In this way, the physical experiments and mathematical models work together to deepen our understanding of nematics. As liquid crystals are a key feature of many modern technologies, Akhshay and Joseph's discoveries are likely to contribute to important technological advances in the future.

ABOUT SOFT MATTER PHYSICS

Soft matter (which includes just about anything squishy) is fascinating at the molecular level because it includes both elements of order and disorder. The realm of soft matter physics investigates materials that lie between ordered solids and disordered liquids. To picture this, imagine people were molecules. A solid would look like a parading army, with every soldier perfectly in line, and a liquid would be a city centre where everybody is going their own way and doing their own thing. Soft matter is more like a party – most people are split up into groups, but the groups can change or merge into each other.

The fun thing about a party is that a small change in conditions (perhaps a new song starts to play) can cause a sudden and dramatic change in the people (everybody gets up onto the dancefloor). The same is true of soft matter, and this is one reason that physicists are fascinated by it. For example, a small change in voltage across a nematic can transform its optical properties.

WHERE CAN YOU SEE SOFT MATTER PHYSICS IN ACTION?

The molecules in soft matter sometimes seem to take on a life of their own. Under the right conditions, they can combine to create complex structures, and life could not exist without this phenomenon. Because of this, soft matter physics is often seen as the 'physics of life', and the quickest way to see it in action is to take a look in the mirror and smile. The protein powering your muscles as you smile works using soft matter physics!

Other natural and artificial examples of soft matter include gels, paints, soap, blood, cosmetics and ice cream. These materials are studied by scientists from various disciplines, including mathematicians, physicists, chemists, biologists and engineers, highlighting the many different routes into the field of soft matter physics.

EXPLORE CAREERS IN PHYSICS AND MATHEMATICS

- From climate science and healthcare to business and robotics, a degree in physics can take you just about anywhere. Find out more about physics career paths at the Institute of Physics: **www.iop.org/careers-physics/your-future-with-physics/career-paths**
- Not sure if university is for you? There are plenty of other ways to start your career in physics. Learn more about apprenticeships and vocational roles: **www.iop.org/careers-physics/your-future-with-physics/vocational**
- Applied mathematicians also work in a wide range of well-paid jobs. "Even if you don't end up working in research, a mathematics degree is a fantastic asset for working in so many industries, including finance and engineering," says Joseph. See where a maths degree could take you: **www.mathscareers.org.uk/careers**

PATHWAY FROM SCHOOL TO PHYSICS OR MATHEMATICS

- Studying maths and physics at school will enable you to study maths or physics at university. If you are interested in soft matter, it would also be good to study another science, such as chemistry or biology.
- Building mathematical models and analysing physical experiments require coding skills, so computer studies may also be useful.
- Most universities offer undergraduate degrees in physics or mathematics, or joint degrees in both subjects. Some may offer specific degrees in experimental physics and/or applied mathematics, though these may be at postgraduate level.
- To work in academia, you will need to complete a PhD, but physics and mathematics skills and knowledge are also important for many other research jobs and careers in industry.

HOW DID AKHSHAY BECOME AN EXPERIMENTAL PHYSICIST?

I had a lot of different interests when I was younger, but none of them were science! That was until I performed some zoology experiments with my dad in our home lab. It was surprising for me to see how some species can regrow missing parts within days.

I love the wide applicability of physics. Everything in natural science can be reduced to physics. Isn't it cool that by understanding physics, you can know the past, present and future of a system? I think you are always a physicist, whatever field of science you work in.

Experimental physics is all about understanding and observing the mysteries of nature. These mysteries are coded in the language of nature – maths. As an experimental physicist, I can observe phenomena, but to decipher them I need mathematical models. This is why our collaboration, between physicist and mathematician, is crucial for unravelling how physical systems behave. Physicists focus on observing the effect, then mathematicians help to answer why the effect is happening.

The most rewarding part of my job is being in the lab. It's amazing to see the science right in front of your eyes. I also like being a scientist because every working day is different, it's not a monotonous 9-to-5 job – it's full of fun! The most challenging part of my work is turning ideas into real physical experiments.

Throughout my academic journey, I have been fortunate to receive many scholarships to support my research. I don't have a defined long-term ambition. I like doing science and so want to pursue this for my lifetime. I hope to be remembered for my work.

Outside of work I enjoy travelling and exploring different places. Apart from this, I like watching historical series and playing games.

AKHSHAY'S TOP TIPS

1. Learn by doing. It's good to have formal education in a specialist field of science, but it's not a necessity.
2. Hunt around for different courses by talking to teachers and students to figure out what interests you.
3. Be curious and enjoy science.

HOW DID JOSEPH BECOME AN APPLIED MATHEMATICIAN?

I had various interests while at school, mainly football and computer gaming. I don't think science and mathematics became an interest until I approached my exams when I was 16. It was around that point I started to realise I enjoyed these subjects. Exams in these subjects made me feel competitive in the same way that football and computer gaming always had.

My dad gave me a book by the travel writer Bill Bryson called *A Short History of Nearly Everything*, and I remember being amazed by the explanations of the big bang and the atom. This book left me wanting to learn more about physics, so I kept reading. I read *A Brief History of Time* by Stephen Hawking and *Physics of the Impossible* by Michio Kaku. Ultimately, it was these books that inspired me to study physics at university. Studying physics then showed me that to understand physics, you must understand maths. So really, physics inspired me to become a mathematician.

The most rewarding part of being a mathematician is getting an insight into how the world works. With a pen, a pad of paper and a computer, I can unravel how a physical system behaves with the tools that mathematics provides. I think it's satisfying and a great privilege to have the skills to understand and discover how the world works.

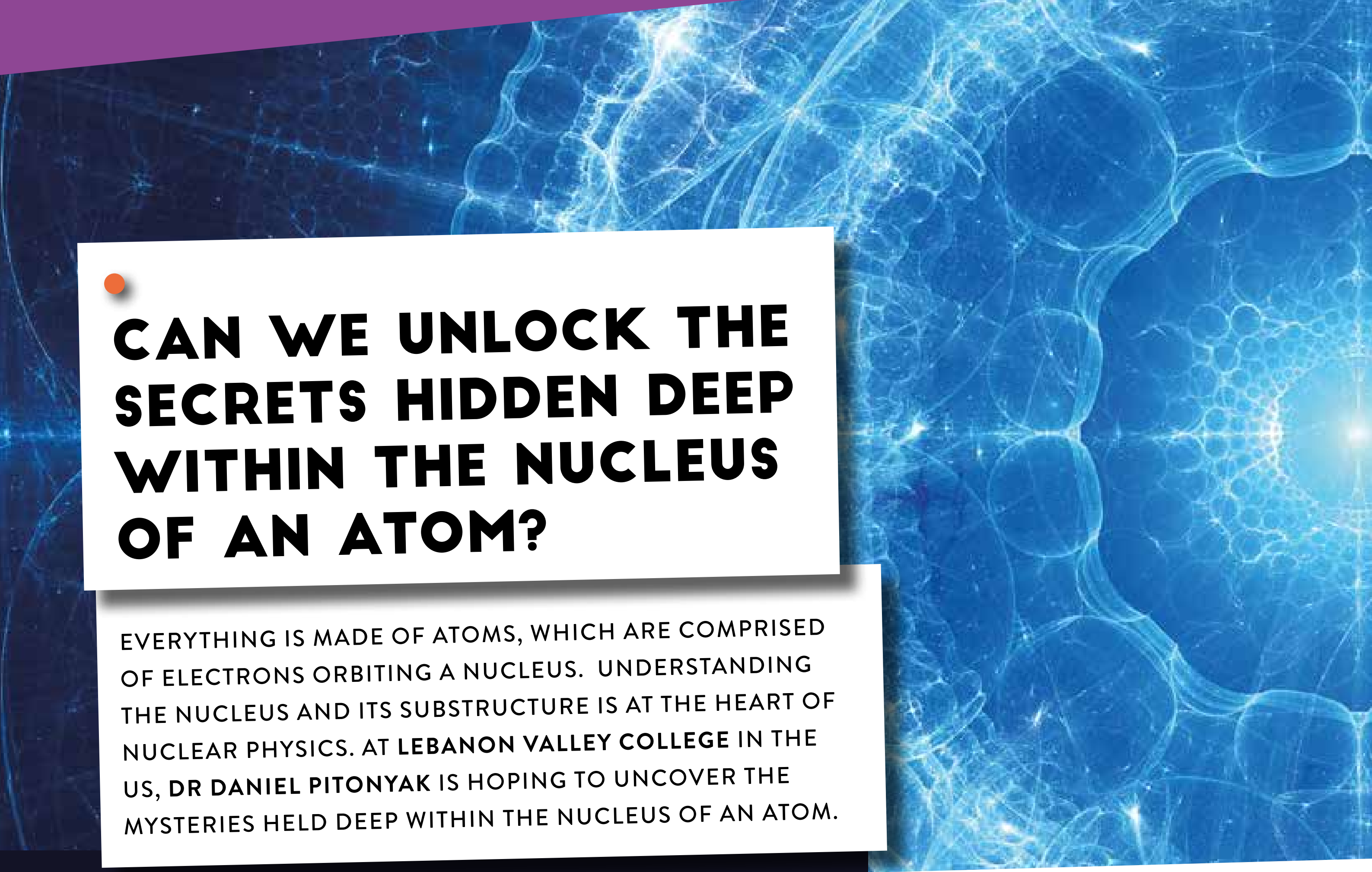
The most challenging part of being a mathematician isn't the maths, it's the writing! Communicating scientific research is a really hard skill. It requires skills that don't always come naturally to mathematicians.

The highlights of my career were completing my PhD and receiving the British Liquid Crystal Society Young Scientist Award. These achievements are a great reminder of what I have contributed to my field. I don't have too many ambitions for the future. I'd like to be happy and work on science that interests me, but that's all I'm sure of.

Out of work, I spend time with my girlfriend and our golden retriever, Hugo. I still find some time to play computer games and follow the football.

JOSEPH'S TOP TIPS

1. Read popular non-fiction books in areas you enjoy at school. This is a great way to get interested in science.
2. If you want to learn more, explore the resources provided by official bodies such as the Institute of Physics or the Institute of Mathematics and its Applications.



CAN WE UNLOCK THE SECRETS HIDDEN DEEP WITHIN THE NUCLEUS OF AN ATOM?

EVERYTHING IS MADE OF ATOMS, WHICH ARE COMPRISED OF ELECTRONS ORBITING A NUCLEUS. UNDERSTANDING THE NUCLEUS AND ITS SUBSTRUCTURE IS AT THE HEART OF NUCLEAR PHYSICS. AT **LEBANON VALLEY COLLEGE** IN THE US, **DR DANIEL PITONYAK** IS HOPING TO UNCOVER THE MYSTERIES HELD DEEP WITHIN THE NUCLEUS OF AN ATOM.

TALK LIKE A NUCLEAR PHYSICIST

PROTON – a positively charged particle in an atom's nucleus

NEUTRON – a neutral particle (one that has no charge) in an atom's nucleus

HADRONS – the collective name for any particle that interacts via the strong nuclear force, e.g., protons and neutrons

ELECTRON – a negatively charged particle orbiting an atom's nucleus

QUARKS – particles inside hadrons, e.g., protons are made of three quarks

GLUONS – particles that hold quarks together inside of hadrons

PARTONS – the collective name for quarks and gluons

QUANTUM CHROMODYNAMICS – the theory that describes how quarks and gluons interact through the strong nuclear force

SPIN – a quantum-mechanical property of particles, similar to the angular momentum of a sphere rotating on its axis, which has the effect of creating a bar magnet within the particle

Full of exotic-sounding particles, and existing on a scale billions of times smaller than the width of a human hair, the world of nuclear physics can be daunting and bewildering. Until the turn of the 20th century, it was generally believed that everything was made of atoms, and that these atoms were the fundamental units of matter. Indeed, the word atom comes from the ancient Greek word *'atomos'*, meaning 'indivisible'.

However, thanks to the work of nuclear physicists like J.J. Thomson and Ernest Rutherford, we now know that atoms are composed of even smaller particles. Each atom is comprised of electrons orbiting a very small, dense nucleus made up of protons and neutrons. And these protons and neutrons can then be split into smaller components still, called quarks. Quarks are a type of 'elementary particle' that cannot be further subdivided.

This is where nuclear physics starts to get more complex. Quarks come in six different types, or 'flavours', – up, down, top, bottom, strange and charm – and they are held together by gluons, another type of elementary particle. Collectively, quarks and gluons are known as partons. The larger particles composed of quarks and gluons (e.g., protons and neutrons) are collectively known as hadrons.

Confused yet? If you are struggling to follow this, do not panic! Even seasoned physicists, like Dr Daniel Pitonyak from Lebanon Valley College, are still working hard to unravel the mysteries of this strange subatomic realm. Daniel's research lies within the field of high-energy nuclear physics, which investigates how parton interactions and motions influence the internal structure of hadrons.

QUANTUM CHROMODYNAMICS

Some particles, like protons and electrons, carry an electric charge which allows them to interact via electric and magnetic forces by exchanging photons. Quarks and gluons carry another type of charge, known as a colour charge, which allows them to interact via the strong nuclear force. It is these interactions that the theory of quantum chromodynamics sets out to describe.

Since hadrons are composed of quarks and gluons, all their properties must arise from and be determined by their constituent partons. For example, we should be able to explain the proton's spin in terms of the quarks and gluons within it.

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DR DANIEL PITONYAK

Assistant Professor of Physics,
Lebanon Valley College, USA

FIELD OF RESEARCH

Nuclear Physics

RESEARCH PROJECT

Investigating the 3D structure of hadrons and the origin of the proton's spin

FUNDER

US National Science Foundation (NSF)

This work is supported by the NSF, under award number PHY-2011763. The contents are solely the responsibility of the authors and do not necessarily represent the official views of the NSF.

WHAT IS SPIN?

Spin is a fundamental property of a particle, like its mass or charge, and is a measure of its intrinsic angular momentum. "The particle is not literally rotating," explains Daniel. "The spin of a particle has the effect of creating a tiny bar magnet inside it that can respond to a magnetic field."

The value of a particle's spin must follow certain rules. It must be either a whole number (1, 2, 3, etc.) or half a whole number (1/2, 3/2, 5/2, etc.) multiple of $\hbar$ (pronounced 'h-bar'), a fundamental constant that shows up in quantum mechanics. Protons, neutrons, electrons and quarks all have a spin of $\hbar/2$, while photons and gluons have a spin of $\hbar$.

WHAT CAUSES A PROTON'S SPIN?

"Typically, spin is measured by observing the direction that a particle is deflected when passing through a magnetic field," says Daniel. One of the main aims of his research is to determine the source of the proton's spin. "Since a proton is composed of quarks and gluons, its spin of $\hbar/2$ must arise from its partons," he explains.

There are two ways in which the partons (quarks and gluons) contribute to the proton's spin. Firstly, the partons themselves carry spin and this is transferred to the proton. Secondly, the partons are moving around inside the proton. This creates angular momentum which also contributes to the proton's spin. The sum of the partons' spins and the angular momenta created by their movement must add up to $\hbar/2$. "However, exactly how much comes from each component remains an open question," says Daniel.

By analysing the results of nuclear physics experiments, it has been determined that 30% of the proton's spin comes from the quarks' spins and 40% comes from the gluons' spins. However, more precise measurements are needed to increase the accuracy of these values. Daniel works on calculating how much spin comes from quarks and gluons that carry only a small fraction of the proton's momentum, which is difficult to access through current experiments.

WHAT EXPERIMENTS ALLOW DANIEL TO STUDY SUCH TINY PARTICLES?

"Partons exist at length scales that are extremely small," says Daniel. "We cannot simply place a proton under an ordinary microscope and see the partons moving around inside." Instead, experimental physicists must smash protons together at incredibly high speeds. These high-energy collisions are conducted in huge particle accelerators, several miles in circumference, that can accelerate protons close to the speed of light. When the protons collide, their partons are ejected, allowing physicists to detect the hadrons they form.

Data from these experiments allow Daniel to better understand the internal structure of hadrons through functions that encode what is going on before and after the collisions. He writes code based on calculations in quantum chromodynamics of how quarks and gluons interact when protons collide, to numerically model the results of these high-energy collisions. He uses algorithms and computational techniques to determine what parameters produce models that best fit the experimental data. From these models, Daniel can discover how the partons are distributed and move within the protons and create images of their 3-dimensional (3D) structure.

WHAT IS THE ELECTRON-ION COLLIDER?

The Electron-Ion Collider (EIC) is a particle accelerator, recently commissioned by the US Department of Energy, which will offer unprecedented insight into the internal structure of hadrons. Thousands of physicists from around the world have been collaborating to design and create the EIC, including Daniel. "I have been involved in analysing how the specifications of the EIC will quantitatively impact our current understanding of the 3D structure of hadrons and how much of the proton's spin arises from quarks and gluons, to ensure the collider is built in a way that maximises its scientific outcomes," he explains.

The construction of the EIC will offer nuclear physicists the chance to advance their research. In the meantime, Daniel's next steps involve creating more complex models that can account for phenomena such as gluon radiation. This will allow him to include additional experimental data in his analyses and make more precise predictions.

WHY IS THIS RESEARCH IMPORTANT?

"This research attempts to understand the most elementary structure of visible matter in our Universe," says Daniel. "It's what we are made of at a fundamental level. Moreover, this research involves young scientists who receive the training necessary to branch out into other STEM fields or areas of physics research. Developing and sustaining a scientific workforce is crucial for creating new technologies and solving the critical problems that face our world."

ABOUT NUCLEAR PHYSICS

Nuclear physics is the field of science that studies the atomic nucleus, its components and their interactions. Despite its complexity, nuclear physics has many real-world applications. Some of these applications are stumbled upon during something known as 'blue skies' research. Blue skies research is conducted without real-world applications in mind and is instead led by curiosity and the quest for deeper insight into the nature of reality. Often, fundamental research such as this leads to scientific breakthroughs that no one anticipated.

There are still many open questions that nuclear physics has yet to answer. "With the Electron-Ion Collider set to be completed in the early 2030s, there are decades of work ahead of us," says Daniel. "The young people of today who become involved in this field will eventually be at the forefront of it."

WHAT TOPICS DO NUCLEAR PHYSICISTS INVESTIGATE?

"Nuclear physics is a broad area of research," says Daniel. "It investigates the structure of atomic nuclei and their interactions, as well as applications to technology." The research of nuclear physicists can range from studying the substructure of nuclei to investigating the creation of matter in the early Universe and the inner workings of stars. Some nuclear physicists study applications in medical imaging and cancer treatments, while others focus on alternative energy and other uses of radioactive decay.

WHAT ARE THE REWARDS AND CHALLENGES OF NUCLEAR PHYSICS RESEARCH?

"I enjoy working on unsolved problems," says Daniel. Through his work, he is adding to our knowledge of the internal structure of matter at the most fundamental level. Daniel also enjoys the process of discovering new knowledge, despite its difficulties. "Each project has its own challenges, obstacles and complexities," he says. "Overcoming these to find a solution that helps our field to progress is very rewarding."

As is so often the case with research, there is not always a clear and direct path towards the end of a project. Unexpected issues can arise, and results may contradict previous data and theories. Solving these problems may need technical solutions, such as creating new code, or looking at the results from different perspectives.

THE IMPORTANCE OF COMPUTATIONAL AND PROGRAMMING SKILLS

Physicists need to be able to take intricate formulas and complex data sets, then write computer code for them in a logical and efficient manner. Programming is vital in many areas of science. Developing an understanding of how coding languages work and practicing on smaller problems is a great way to develop this skill.

PATHWAY FROM SCHOOL TO NUCLEAR PHYSICS

- Taking physics classes in high school is the first step to exploring your interest in the subject.
- "Any area of physics requires strong mathematical, computational and experimental skills," says Daniel. Develop these by taking classes such as mathematics, calculus and programming.
- Most universities offer degrees in physics, which will provide the most direct route to a career in nuclear physics. A physics degree will involve courses in advanced theoretical, computational and experimental physics topics and advanced mathematics.

EXPLORE CAREERS IN NUCLEAR PHYSICS

- The applications for nuclear physics are vast and varied. Because of this, you could find yourself working in fields as diverse as energy, medicine, agriculture or even archaeology.
- The US Department of Energy's Nuclear Physics website (**www.energy.gov/science/np/nuclear-physics**) is a great place to explore the applications of nuclear physics.
- The European Nuclear Society (**www.euronuclear.org**) gives a broad overview of the areas covered in nuclear physics and discusses possible career options.


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HOW DID DANIEL BECOME A NUCLEAR PHYSICIST?

WHAT WERE YOUR INTERESTS WHEN YOU WERE YOUNGER?

From an early age, I was always interested in math and science, and enjoyed and excelled in both subjects. When I took my first physics class in high school, I knew this was what I wanted to pursue. It is the ultimate combination of math and science.

WHO OR WHAT INSPIRED YOU TO BECOME A NUCLEAR PHYSICIST?

In my first year of college, I read a book called *The Elegant Universe* by Dr Brian Greene and became fascinated with understanding the structure of matter at the level of elementary particles. One of my undergraduate professors, Dr Scott Walck, helped me work through a textbook on elementary particle physics, even though it was not a course taught at my college. My PhD advisor, Dr Andreas Metz, exposed me to some of the outstanding problems in understanding the substructure of hadrons and helped me to develop the skills I needed to continue in this area of research. All of these played a role in inspiring me to pursue a career as a nuclear physicist.

> **"WHEN I TOOK MY FIRST PHYSICS CLASS IN HIGH SCHOOL, I KNEW THIS WAS WHAT I WANTED TO PURSUE. IT IS THE ULTIMATE COMBINATION OF MATH AND SCIENCE."**

WHAT ARE YOUR PROUDEST CAREER ACHIEVEMENTS SO FAR?

The first achievement I am proud of is winning the 2015 Dissertation Award from the American Physical Society Group on Hadronic Physics, for research I performed during my PhD. The second is receiving a National Science Foundation grant for my research on the 3D structure of hadrons.

WHAT ARE YOUR AMBITIONS FOR THE FUTURE?

I hope to continue receiving funding for my work, publishing impactful papers, and motivating students to enter careers in STEM fields.

WHAT IS YOUR FAVOURITE FACT ABOUT ATOMS?

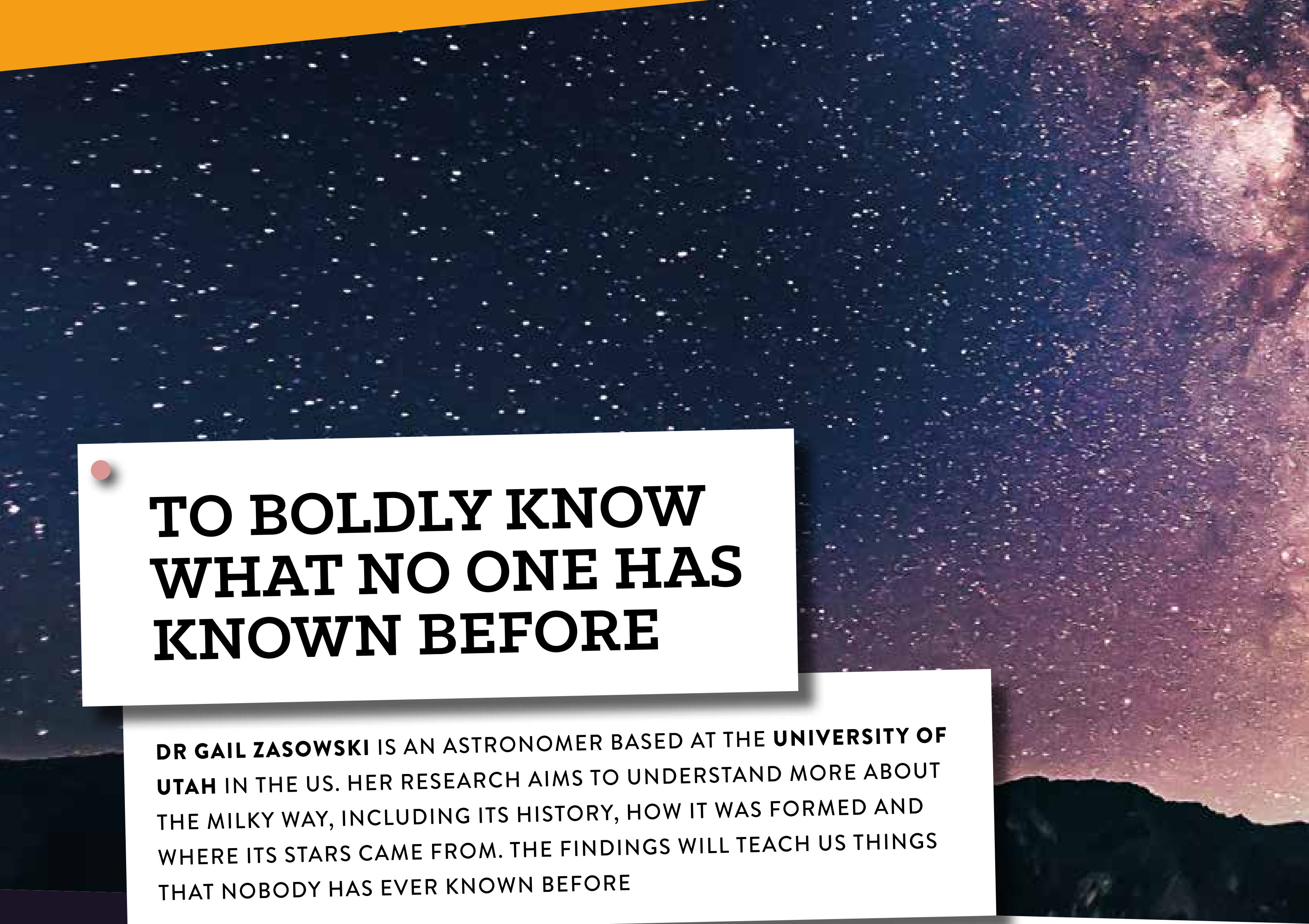
The nucleus of an atom is very dense, meaning it has a tremendous amount of mass packed into an extremely small volume. If you had a tablespoon of nuclear matter, it would weigh over 1 billion tons!

DANIEL'S TOP TIPS

01 Get involved in science-based after-school activities or summer camps.

02 Take as many advanced mathematics classes as you can and study computer programming.

03 At college, get involved in research with faculty members as soon as you can, even if it isn't the exact field that you want to get into. The experience will be invaluable.



TO BOLDLY KNOW WHAT NO ONE HAS KNOWN BEFORE

DR GAIL ZASOWSKI IS AN ASTRONOMER BASED AT THE **UNIVERSITY OF UTAH** IN THE US. HER RESEARCH AIMS TO UNDERSTAND MORE ABOUT THE MILKY WAY, INCLUDING ITS HISTORY, HOW IT WAS FORMED AND WHERE ITS STARS CAME FROM. THE FINDINGS WILL TEACH US THINGS THAT NOBODY HAS EVER KNOWN BEFORE

TALK LIKE AN ASTRONOMER

THE BIG BANG – prevailing cosmological model explaining the existence of the observable Universe, from the earliest known periods through its subsequent large-scale evolution

GALAXY – gravitationally bound system of stars, stellar remnants, interstellar gas, dust and dark matter

GALAXY EVOLUTION – the physical changes and mechanisms that led to present-day galaxies

STARS – massive self-luminous celestial bodies of gas that shine by radiation derived from their internal energy sources

According to Captain James Kirk, space is the final frontier (although oceanographers might have something to say about that). Beyond the Earth's atmosphere, there is a vast area of the Universe that we will likely never completely understand, despite the best efforts of mathematicians, physicists and astronomers.

However, rather than being a source of frustration, space represents infinite possibility, which is why astronomers like Dr Gail Zasowski, based at the University of Utah in the US, enjoy what they do in their professional lives. Gail is an astronomer with a particular interest in understanding where and when our Milky Way galaxy formed its 100 billion stars. Her research will help us understand how the infant Milky Way grew into the massive spiral galaxy that we see today.

WHAT ARE OUR CURRENT LIMITATIONS REGARDING UNDERSTANDING THE HISTORY OF OUR GALAXY?

Ironically, the main limitation to our understanding is closely related to the main advantage: that we are embedded inside the Galaxy. It can be thought of as the difference between looking at a map of a city and standing on a street in that city. "Looking at a map is like looking at other galaxies – we can see the overall shape and structure, where the business and residential areas are, and so on," explains Gail. "But standing in that city has historically been like studying the Milky Way – we can't see the pattern of streets or what the next neighbourhood looks like, but we can see the people and the shop windows, smell the smells, hear the sounds."

However, in recent years, astronomers have been able to peer farther into the Milky Way than ever before. A lot of the difficulty in observing our galaxy is because of the thick clouds of gas and dust that fill the disc part of the Milky Way and block the starlight behind them. But some surveys, including the second generation of the Apache Point Observatory Galactic Evolution Experiment in the Sloan Digital Sky Survey III and IV projects (**www.sdss.org**), use infrared light to study the stars, which is much less affected by the intervening dust. The problem of perspective still exists, but astronomers are getting closer to being able to characterise the Milky Way in the same way as external galaxies.

WHY IS THE MILKY WAY SO IMPORTANT?

We can observe the Milky Way at a higher resolution than other galaxies because of our proximity to it. Although there are some challenges as previously noted, we can observe the small-scale building blocks of galaxies, such as individual stars and small gas clouds. "These observations have

DR GAIL ZASOWSKI

Department of Physics and Astronomy, University of Utah, Salt Lake City, USA

FIELD OF RESEARCH

Astronomy and Astrophysics

RESEARCH PROJECT

Understanding where and when the Milky Way galaxy formed its 100 billion stars and how the infant Milky Way grew into the massive spiral galaxy we see today

FUNDERS

US National Science Foundation (NSF), Research Corporation for Science Advancement, Heising-Simons Foundation

shaped our understanding of a large fraction of astrophysics, from what happens in the interiors of stars to the ways a whole galaxy can change over billions of years," says Gail. "We then apply this understanding to interpret our observations of other galaxies – where we can't see things at the same level of detail – and create a picture of how galaxies in the Universe, and the Universe itself, have evolved since shortly after the Big Bang."

The 'big-picture' questions Gail and her team are trying to answer include: "Where and when did the Milky Way's stars form?", "What are the main sources of heavy elements in today's Milky Way stars, and when and how were they synthesised?" and "What is the best way to apply what we learn in our Galaxy to understanding what happens in other galaxies?"

Addressing these questions involves answering smaller ones, like: "How old are the stars in a specific part of the Milky Way and what is their chemical makeup?", "What series of evolutionary events could give us this pattern of stellar ages and chemistry?", and "How does the gas and dust between the stars move around throughout these events?"

METHODS, FINDINGS AND SUCCESSES

To uncover what elements are in a star, Gail and her team are part of a larger team that measures the star's light at different wavelengths. Atoms of different elements absorb that light at different wavelengths, so models are fitted to the pattern of absorption compared with wavelength to determine how much of each element is present in the star. These same models also account for the temperature, surface gravity and other properties of the star that are necessary for computing distances and ages.

Gail's group has worked hard to link detailed measurements that can be made in the Milky Way with global measurements that can be made in other galaxies (which are less detailed but cover a higher number of galaxies in different environments with different histories). "It has been very exciting to see many different analyses on stars in different parts of the Milky Way come together in a comprehensive picture of where and when its stars formed, including the influence of gas accretion events billions of years ago, which strongly affected the regions near the Sun (but which probably happened before the Sun formed!)," explains Gail.

"It has also been extremely gratifying to see the students and post-doctoral researchers in my group taking ownership of their work and leading their own projects, often collaborating with each other and with very little input from me. I value the success of the scientific work for increasing our understanding of the Universe and for launching the careers (in and out of academia) of so many hard-working scientists."

WHAT ARE THE LONG-TERM PLANS FOR GAIL'S RESEARCH?

Many of the upcoming datasets – including for the SDSS-V (**www.sdss.org**), the next data releases from ESA's Gaia mission (**sci.esa.int/web/gaia**) and NASA's Roman Space Telescope (**roman.gsfc.nasa.gov**) – will provide ever-larger troves of measurements of the stars in our Milky Way and nearby galaxies.

"I am excited to work on recreating the history of our galaxy – playing the movie of its life, backwards – by mapping out where and when the stars form, how they release their new elements back into the galaxy and how those new elements move around between the stars before being incorporated into the next stellar generations," says Gail. "I love learning things that no one has ever known before."

ABOUT ASTRONOMY

Astronomy is something that surely interests all of us to some degree and is a field that is ready for new discoveries. It was only around 400 years ago that Galileo was chastised for championing Copernican heliocentrism (the belief that the Earth revolved around the Sun). This demonstrates just how ready the field of astronomy is when it comes to new and novel ideas that could fundamentally change our understanding of the ways things are.

WHAT DOES GAIL FIND MORE REWARDING ABOUT HER RESEARCH IN ASTRONOMY?

Perhaps unsurprisingly, Gail loves learning things that no one has ever known before, such as seeing a particular pattern or correlation for the first time. In many ways, astronomy is not centred on answering questions, but on asking questions that no one has thought to ask before. "What I find particularly rewarding is getting to learn all these things about some of the biggest, most beautiful and most unfathomable objects in the Universe," explains Gail.

"By 'unfathomable' I don't mean un-understandable, but rather that we can't truly picture their size, we can't hold something that big or that hot or that old in our minds. Even stars, which we see every night with our eyes, and which are on average rather small and cool compared to other things in the Universe – our brains just aren't set up to imagine those regimes."

WHAT CHALLENGES WILL THE NEXT GENERATION OF ASTRONOMERS FACE?

There are always technical challenges: think about the difficulties of studying space without a telescope! Then think about the first telescopes and how primitive they were. Now think about the telescopes that we have presently and consider how they will one day be seen as primitive! It is a basic fact that we will be able to understand more about space with time simply because of access to improved and better tools.

But then, there are also data challenges. "Our datasets, observational and simulated, are getting increasingly larger, and being able to store this information and access it already requires specialised knowledge," says Gail. "In addition, data is more complex, so understanding how to put all that data into a meaningful physical understanding is a challenge that is unlikely to be solved any time soon, but it's exciting to think that one day it will be."

HOW HAVE OUTREACH AND EDUCATION INITIATIVES, AT THE UNIVERSITY OF UTAH AND ELSEWHERE, HELPED ENCOURAGE YOUNG PEOPLE TO STUDY STEM?

One of the things the team tries to do with these kinds of programmes is to emphasise that science is something that shows up in everyday life. It's not some obscure knowledge that only genius people in lab coats have access to. It affects all of us every day and is something we can all learn about. "We try to do fun projects that show how scientific knowledge, maths and computing manifest themselves in objects and activities that everyone can contribute to," explains Gail. "We want to convey the idea that studying STEM prepares people for a wide range of things in life – not just jobs! If you want to study science as a career, you can do it, even if you don't fit the stereotypical image of what, say, the movies tell us a 'scientist' looks like."

EXPLORE CAREERS IN ASTRONOMY

- For people who are interested in learning more about cutting-edge research, Gail recommends the AstroBites website: **astrobites.org**
- Sea and Sky (**www.seasky.org/astronomy/astronomy-resources.html**) is a website dedicated to providing useful resources for budding astronomers. There is a wealth of information contained on its website, so we recommend you explore it!
- According to National Careers, astronomers in the UK can expect to earn between £15,000 and £60,000 per year, depending on their level of experience: **nationalcareers.service.gov.uk/job-profiles/astronomer**

PATHWAY FROM SCHOOL TO ASTRONOMY

- Gail says that maths and physics are definitely important, but something that is often overlooked is communication skills, especially writing and public speaking. Being able to report and explain complex ideas and analyses in a clear, concise way is incredibly valuable. So, try and take a technical writing or a public speaking class.
- Two or three A levels, or equivalent, including maths and physics.
- You'll need a degree and postgraduate qualification to work as an astronomer. You'll usually need to have achieved a first or a second class (upper) in your degree. Relevant subjects include maths, physics, astrophysics, astronomy and space science.

HOW DID GAIL BECOME AN ASTRONOMER?

WHAT WERE YOUR INTERESTS WHEN YOU WERE GROWING UP?

I've always loved reading, especially science fiction and historical novels. In school, I enjoyed science and language classes the most – I love learning how systems work, both the physical system of the Universe and human systems of language and communication. I'm also an avid outdoor enthusiast and love camping and spending time in nature, especially here in Utah, with its red-rock canyons, deserts and incredibly dark night-time skies!

WHO OR WHAT INSPIRED YOU TO BECOME AN ASTRONOMER?

It wasn't until I was at university that I understood that 'astronomer' was a job that people could have (my earlier schools didn't really push science as a career). I took an introductory astrophysics course during my first year at university, and the combination of the enormity and beauty of the Universe, coupled with actually being able to understand pieces of it with maths and physics, was irresistible.

WHAT ATTRIBUTES HAVE MADE YOU SUCCESSFUL AS AN ASTRONOMER?

Being detail-oriented has been very helpful, I think. A lot of my day-to-day work involves writing code, reading and writing papers, and understanding all the nitty-gritty details of a dataset that might influence our interpretation of our results. Not being able or interested in submerging oneself in those details would make the daily work much more challenging.

Being a people person has also been helpful. Much of the astronomical progress currently is made in collaboration with other people, as simulations and datasets get larger and more complex, and just require so many more individuals to create them. I love working with a team of people on a common project and doing my part to make sure the team is a fun and inclusive place to be, which almost always leads to better science too.

WHAT ARE YOUR PROUDEST CAREER ACHIEVEMENTS SO FAR?

I am very proud of the scientific knowledge that my team and I have contributed to our understanding of the Universe. I am also proud of what I have been able to do in the classroom and broader environment in the field and my department. Both of these were recognised with a Cottrell Scholar Award (**rescorp.org/cottrell-scholars**) in 2021, which honours early-career faculty who have shown excellence in both research and education.

HOW DO YOU DEAL WITH CHALLENGES AT WORK?

Deep breaths! Very few things are solved well if people are worked up or angry. If the science or the data are challenging, I take a step back and think about the root of the problem. Taking a walk or working on something else for a while can be very useful. It's helpful to remember that the Universe isn't trying to be difficult! Often, things are just more complicated than we anticipated they would be, and our job is to make our treatment of the data more sophisticated in response.

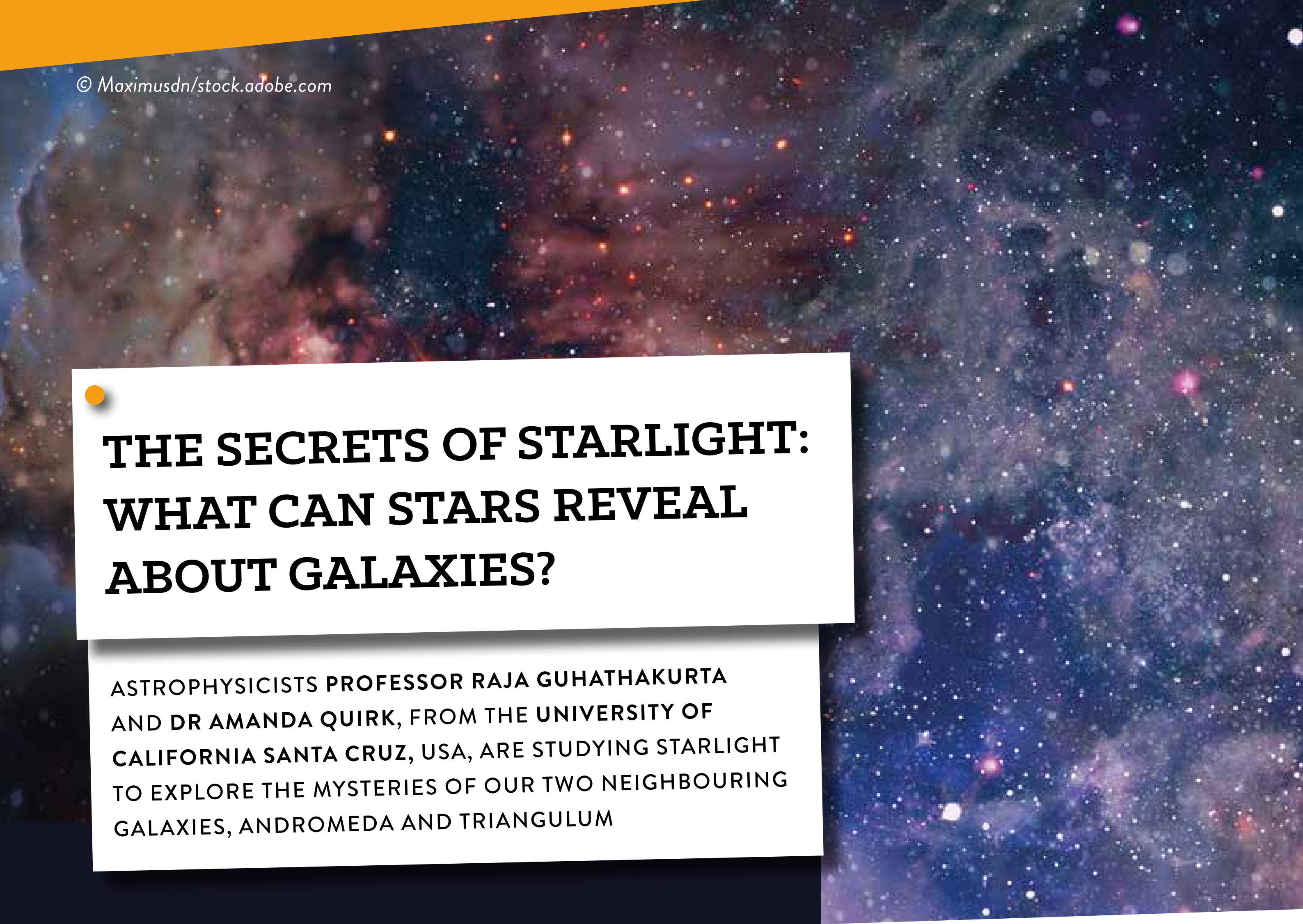
If there are tensions with people causing challenges, I take a similar approach: focus on why people are acting like they are, not the effects on me or my feelings. If someone is behaving inappropriately, that does need to be addressed, but often the root of the conflict is a misunderstanding or miscommunication that a calm, neutral message can resolve.

GAIL'S TOP TIPS

1. Be the kind of person others want to collaborate with! Be respectful, acknowledge others' time and efforts and learn how to communicate professionally and courteously.

2. Be realistic. The job market is difficult now and we don't anticipate it getting much better soon. Pursue your dreams but be open-minded about alternative ways of using your skills.

3. Think about what you really want – studying physics and astronomy gives you knowledge and skills that are useful in a much larger setting than just academia.



THE SECRETS OF STARLIGHT: WHAT CAN STARS REVEAL ABOUT GALAXIES?

ASTROPHYSICISTS **PROFESSOR RAJA GUHATHAKURTA** AND **DR AMANDA QUIRK**, FROM THE **UNIVERSITY OF CALIFORNIA SANTA CRUZ**, USA, ARE STUDYING STARLIGHT TO EXPLORE THE MYSTERIES OF OUR TWO NEIGHBOURING GALAXIES, ANDROMEDA AND TRIANGULUM

TALK LIKE AN ASTROPHYSICIST

GALAXY – a very large collection of gas, dust, billions of stars and planets, and a mysterious substance called dark matter held together by gravity

HUBBLE SPACE TELESCOPE – a space-based astronomical telescope that orbits ~500 km above Earth

LIGHT-YEAR – the distance travelled by light in one year (equal to ~9,000,000,000,000 km)

SPECTROSCOPY – the study of the wavelengths of light from a star

SUPERNOVA – the explosion of a star

WAVELENGTH – the distance between the crests of a light wave, a property we perceive as colour

Professor Raja GuhaThakurta and Dr Amanda Quirk are galactic explorers. From their base at the University of California Santa Cruz, USA, planet Earth, these two astrophysicists study the light released millions of years ago from the Andromeda and Triangulum galaxies. While you might call them stars of science, they would tell you that, in a way, every one of us is a star.

HOW ARE WE MADE OF STARDUST?

More than 96% of your body is made up of just four elements: hydrogen, oxygen, carbon and nitrogen. At the start of the Universe, however, only the simplest of these – hydrogen – existed. All other elements that are essential for life were created within stars.

The centre of a star is a nuclear reactor, where the atoms of lighter elements are fused together to create heavier ones like oxygen and carbon. This reaction releases huge amounts of energy, which is why stars radiate so much heat and light. This energy also stops stars collapsing in on themselves under the pressure of gravity.

However, when a massive star eventually runs out of fuel to power its nuclear reactor, there is nothing left to hold gravity back, and the core of the star implodes. The subsequent bounce causes an almighty blast that sends the heavy elements out into space. Known as a supernova, this is how stardust is created. In a galaxy, gravity causes the stardust created by generations of supernovae to clump together, forming new stars and planets. This is how our own solar system and planet were created. So, were it not for the dust of ancient exploded stars, there would be no such thing as life as we know it.

WHY STUDY OTHER GALAXIES?

We live in a galaxy – the Milky Way – so it may seem odd that Raja and Amanda are more interested in Andromeda and Triangulum, both of which are over 2.5 million light years away. However, it is hard to view a galaxy from inside it.

Imagine you want to take a photo of your school. To get a good view, you would need to stand outside the building. Would this be practical if your school was as big as the Milky Way? The edge of our galaxy is about 1 million light years away, so we cannot send a camera outside the Milky Way to look back at it. Instead, it is easier to look at our neighbours. "Andromeda and Triangulum are both spiral galaxies like the Milky Way," explains Amanda, "so they can give us an idea of how our own galaxy formed and changed over time."

REVEALING THE HIDDEN MESSAGES IN STARLIGHT

Have you ever used a prism to split white light into a rainbow of colours? Astrophysicists do something similar with starlight – they pass it through a narrow slit into a spectrograph which

separates the light according to its wavelength. The amount of light from long (red) to short (blue) wavelengths describes the spectrum of the star and studying this spectrum (a technique known as spectroscopy) can reveal incredible details.

The speed at which a star is moving can be determined by the squashing or stretching of its light to shorter or longer wavelengths. The dominant wavelength is a guide to the star's temperature, as hotter stars tend to glow at shorter wavelengths. And, dips in the spectrum can reveal the star's chemical composition.

Raja and Amanda have been measuring spectra of stars in Andromeda and Triangulum since 2016, using the Keck-II telescope in Hawai'i. This telescope sits at the summit of Maunakea, a dormant volcano and a sacred site to the Indigenous community, so Amanda considers herself "incredibly fortunate" to use the facility for a few nights each year. Before a night at Keck-II, Raja and Amanda use images from the Hubble Space Telescope to identify the stars they want to track so they can point the Keck-II telescope perfectly. The team has now measured spectra of thousands of stars in Triangulum to create the Triangulum Extended (TREX) survey.

THE MYSTERIES OF TRIANGULUM

"Our TREX survey has raised more questions about Triangulum than it has answered!" says Raja. Among the new mysteries is a group of stars in the middle of the galaxy that appear to be 'misbehaving'. While most stars in Triangulum follow a beautiful, orderly pattern like a flock of birds, this unruly bunch are flying around in random directions like a swarm of bees.

The strangest thing is that some of the disorderly stars are relatively young, so they have not yet had time to be disturbed. What has set these 'young and restless' stars into frenzied motion is unclear. Raja and Amanda are continuing to analyse spectra of the stars to see if their chemical makeup can shed light on the galaxy's history.

Another odd thing about Triangulum is that its stars are arranged in an 'S' shape, unlike most galaxies of its size which tend to be arranged as a disc, like a dinner plate. Amanda and Raja are not sure exactly why this is, but suspect Triangulum may have been involved in a galactic collision.

WHAT HAPPENS WHEN GALAXIES COLLIDE?

When two galaxies get close to each other, the stars in one galaxy will be pulled by the gravity of the other. This causes the galaxies to spiral around each other, in a 'dance' lasting billions of years. Eventually they merge into a single galaxy, with a new shape and structure caused by the complex forces of gravity.

Amazingly, nothing actually crashes into anything else when galaxies collide, because the vast majority of a galaxy is empty space. "It's like having two cathedral-sized bubbles, each with a fly in them," explains Amanda. "If you throw these bubbles at each other, the chances of the two flies hitting each other is almost zero."

SHOULD WE BE WORRIED ABOUT A COLLISION WITH ANDROMEDA?

Raja was part of the team that created the first ever digital photo mosaic of the Andromeda galaxy, constructed by stitching together 57 images taken by a ground-based telescope. Subsequent spectroscopy based on wider area images led to the surprising discovery that Andromeda is five times bigger than previously thought. The team determined this by analysing spectra of bright points in wide area images to deduce if each point was an Andromeda star, a Milky Way star in the foreground, or a distant galaxy in the background.

Since then, astronomers have generated much more detailed pictures of Andromeda by combining high-resolution images taken by the Hubble Space Telescope. These new images held an even bigger surprise – Andromeda is heading straight for us. Previously, we knew it was getting closer, but had no idea it was on a collision course. The team Raja belongs to showed this must be the case by comparing two images, taken seven years apart, of stars in Andromeda against the background of distant galaxies. Raja likens this to "watching an insect creep slowly across your wall, using patterned wallpaper as a reference."

The results showed very little movement left or right, up or down. The only conclusion is that Andromeda is moving in a direct line towards the Milky Way. However, the collision is not due for another 4.5 billion years. By then, our Sun will have increased in brightness and made it too hot for liquid water on Earth, so it is unlikely anybody will be alive to see it happen.

PROFESSOR RAJA GUHATHAKURTA

Professor of Astronomy and Astrophysics

DR AMANDA QUIRK

Former PhD Researcher

University of California Santa Cruz, USA

FIELD OF RESEARCH

Galaxy Evolution

RESEARCH PROJECT

Investigating the movement of stars in the Andromeda and Triangulum galaxies

FUNDERS

US National Science Foundation (NSF), NASA/Space Telescope Science Institute, Google Engineering Education, Amazon Web Services, Hopper-Dean Foundation, Viram Foundation, ARCS Foundation

HOW DID RAJA BECOME AN ASTROPHYSICIST?

My main interest when I was growing up was art. I loved painting, and still do. My mother was a wonderful artist, as was my older sister and grandmother, so I was surrounded by strong artistic influences. I was also interested in sports and enjoyed both watching and playing lots of different sports.

I liked all kinds of science when I was at school – biology, chemistry, physics. Watching *Life on Earth*, an ecology documentary series narrated by David Attenborough, encouraged me to become a scientist, and trips to the planetarium inspired my love for the stars and motivated me to study astronomy.

After completing my bachelor's degree in India, I came to the US for my PhD. Switching between two very different educational systems was a huge challenge as I was ill-prepared for the style of learning in graduate school. I was used to solving maths, physics, and chemistry problems, but they were invariably problems that someone had set and, therefore, knew the answer to. The open-ended nature of problem solving for a PhD was completely new to me, and this is one of the things that inspired me to establish the Science Internship Program.

The highlight of my career actually has nothing to do with astronomy! Recently, I was offered my first solo art show. Nothing has made me prouder and happier than this opportunity to display my artwork for the public to see.

I think there are parallels between art and astronomy. Both involve observing fine details (I paint and draw portraits of people and animals), creativity, and problem solving. As an astronomer, I envisage how I want to conduct an experiment, but commonly run into issues that must be overcome. As an artist, I envisage how I want to draw a portrait, but sometimes the shading won't work, or the piece won't look as I imagined.

I love the fact that astronomy allows us to look back in time. I think it is fascinating that the light we see in our telescopes on Earth left Andromeda millions of years ago.

RAJA'S TOP TIPS

1. Be patient with yourself. You never know when you will find your passion, but that time will come.

2. Follow things you are interested in, and don't do things just because other people are doing them.

3. If you work hard at something and you really believe in it, good things will happen.

HOW DID AMANDA BECOME AN ASTROPHYSICIST?

I painted a lot as a kid and I swam whenever I could. I had a lot of chronic pain growing up, and swimming was one of the biggest reliefs I had. I was always trying to escape Earth's gravity, because it caused my joints to hurt. These days, I like to go to the beach and draw, and I love snorkelling, though the ocean around Santa Cruz is too cold for me!

I think seeing Saturn in a telescope for the first time was what got me hooked on astronomy. I was at a science centre and my first thought was "How can this be real?" It looked too much like the images I had seen in my textbooks. It was a really inspiring moment for me.

Growing up, I couldn't name a disabled scientist, even though there are many. That always made me feel isolated, so I want to lessen that isolation for others. I created the Graduate Disability Community Group at UCSC, where disabled graduate students can come together. This was a community I had really been missing; now, it's great to feel fully understood by peers. I have also been advocating for STEM programmes to develop more flexibility and to be more accessible.

I want STEM to be a truly inclusive space – anyone who wants to pursue STEM should be able to. Disabled people often have to come up with creative solutions in their lives, and this creativity is really valuable in science. If more disabled scientists are supported in the field, it will lead to more fascinating discoveries.

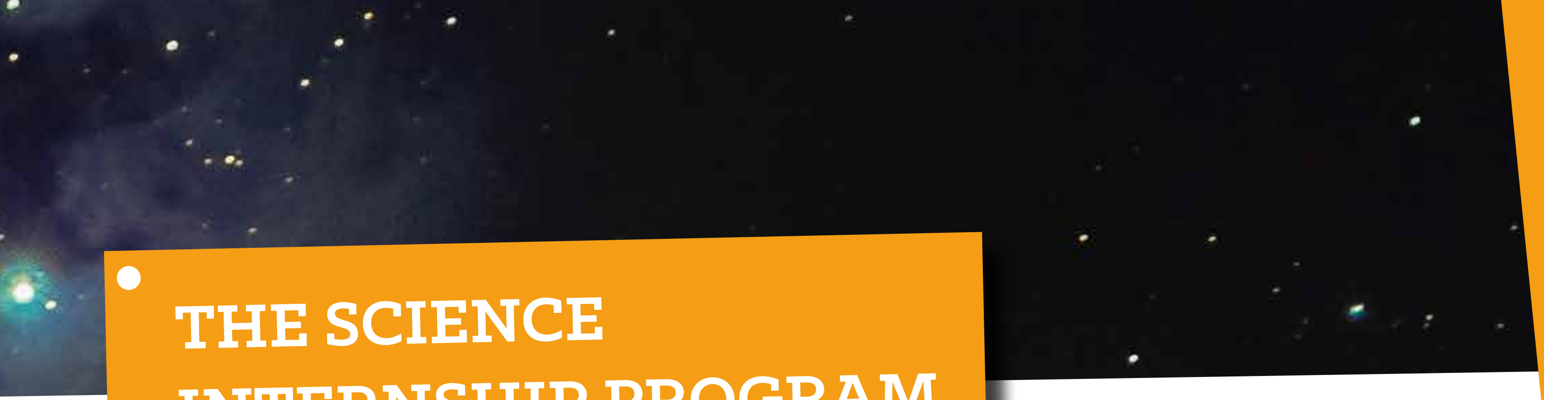
I work with the Project for Inmate Education programme at UCSC, where I teach algebra and astronomy in Santa Cruz jail facilities. I have developed valuable teaching skills through this opportunity as I have to be a dynamic teacher to ensure I keep everyone engaged, while providing enough background information for students with less familiarity with the concepts. The students enjoy the classes because they allow them to exercise part of their critical thinking that otherwise isn't used in their day-to-day routines.

AMANDA'S TOP TIPS

1. Find a solid support network. In every field there are kind people who will help you be yourself and succeed.

2. Keep hobbies outside of work. It's important to remember that you are worth more than the work you do and to take meaningful breaks.

3. The journey through high school and college is the hardest part, in my opinion. Give yourself credit for the work you're doing at all stages!



THE SCIENCE INTERNSHIP PROGRAM

Raja is the founder of the Science Internship Program (SIP), which gives high school students the chance to work on authentic cutting-edge research at the University of California Santa Cruz. While receiving training from academics to develop their research skills, students complete a project over the summer, allowing them to contribute to scientific discoveries.

HOW DID SIP START?

In 2009, Raja was asked by a local teacher if he would host a few students in his lab, so they could do some astronomy research. He saw that this could benefit everyone – the students would learn what it is like to conduct research, while he would get help analysing his data. That year, three students analysed spectra of stars in Andromeda. One studied the chemical elements in the stars, another calculated how fast the stars were moving, and the third determined which stars were part of the Andromeda galaxy and which were in the Milky Way.

WHY IS IT OKAY TO FAIL?

Unlike in school, where you will be asked to answer questions that have been set by your teacher or textbook, scientists are trying to solve puzzles that nobody has solved before. This means that no one knows the answer, and scientists often get stuck or make mistakes as they search for a solution.

At school, you might feel like you have failed if you do not find the answer, but this is a crucial part of research. "It is important for students to learn that failing is part of the journey to discovery," explains Raja. Behind every big discovery are a thousand 'failed' experiments, so the essential thing is to keep on experimenting.

Students participating in SIP learn the importance of this process of trial and error. "Students are tasked with solving problems that no one has done before, so they need to use their critical thinking skills to find solutions," says Raja. "These solutions may or may not work, but both outcomes are equally useful."

HOW HAS SIP GROWN?

Since Raja invited three students into his lab, SIP has grown every year. By 2022, there were 95 academics hosting 326 students, covering 20 different subjects. The programme has worked hard to become more inclusive by reaching out to students of colour, those from low-income families, and first-generation college aspirants, all of whom face additional barriers to going to university. When the COVID-19 pandemic forced SIP to move online, this opened the programme to students around the world, and Raja hopes that in future SIP will consist of a mix of online and in-person research projects.

"It is important for students to learn that failing is part of the journey to discovery," explains Raja. Behind every big discovery are a thousand 'failed' experiments, so the essential thing is to keep on experimenting.

WHAT CAN CULTURES REVEAL ABOUT STARS?

NATIVE SKYWATCHERS

Humans have been looking up at the stars long before the Hubble Space Telescope began taking high-resolution images of Andromeda. For tens of thousands of years, communities and civilisations have observed the night sky and tried to understand what is up there. This means the scientific method is only one way of describing the Universe – many cultures have traditional knowledge and beliefs that often hold a deep connection between humans and the stars.

While much of this ancient understanding has been lost due to colonisation and as city lights pollute the night skies, Professor Annette S. Lee, director of Native Skywatchers, is working hard to ensure we do not forget this knowledge.

The aim of Native Skywatchers is to revitalise Indigenous star and Earth knowledge with community-based leadership and from the narrative of the Indigenous voice. In addition, Native Skywatchers encourages people to appreciate both Indigenous knowledge systems of the stars and astronomy, and to forge connections between Indigenous groups and scientists.

WHAT IS TWO-EYED SEEING?

The idea that these two ways of looking at the world, from an Indigenous viewpoint and from a 'scientific' viewpoint, are equally important is known as 'Two-Eyed Seeing', or *Etuaptmumk* in the language of the Mi'kmaq Indigenous peoples.

According to Mi'kmaq elder, Albert Marshall, "Two-Eyed Seeing is learning to see from one eye with the strengths of Indigenous knowledges and ways of knowing, and from the other eye with the strengths of Western knowledges and ways of knowing... but most importantly, learning to use both these eyes together, for the benefit of all."

As the US becomes more diverse, Annette feels Two-Eyed Seeing is more important than ever. "Only when we equally value all the voices of people from diverse perspectives can we begin to tackle some of the crises we are facing today," she says.

WHAT DOES NATIVE SKYWATCHERS DO?

Building on insider relationships, Native Skywatchers records and shares Indigenous knowledge of the stars through a multidisciplinary approach at the intersection of science, art and culture, based on the frameworks of experiential learning, digital storytelling and culturally responsive pedagogy. "By leveraging both the power of science and the power of digital media, enormous change is possible," says Annette. In its workshops, Native Skywatchers has brought together young and old Indigenous knowledge keepers, language and cultural experts, scientists, artists, teachers and communities to share their understandings of astronomy and Indigenous science, and, more importantly, to build community.

WHAT CAN WE SEE IN THE STARS?

Annette and the Native Skywatchers team have researched and designed star maps, to provide a first-glance introduction to Two-Eyed Seeing (**www.annettelee.com/index.php/portfolio/star-maps**). The maps themselves are from the Western science system and are only the beginning 'baby steps' to understanding the larger and deeper philosophical cosmology and practice that is deeply rooted in Indigenous knowledge systems.

"For example, there are many important D(L)akota teachings that relate to To/Tuŋ Wiŋ (Blue/Birth Woman)," explains Annette. "She resides at an important doorway in the stars, right at the centre of the scoop of what non-Indigenous US folks call the Big Dipper. This constellation is part of important D(L)akota teachings of origin, of how we come from the stars. To/Tuŋ Wiŋ is a doorway between the spirit world and the material world, helping those who are coming into (being born) or leaving (dying) this human journey." This same group of seven bright stars is also known as the Wičakiyuhapi Wašihdapi or 'Stretchers and the Mourners'.

Indigenous constellations are brightly coloured on the Native Skywatchers star maps and the Greek constellations are indicated more subtly, located in the background for reference. These maps begin to show a deeply different and layered Indigenous way of looking at the sky through an Ojibwe, D(L)akota, and Ininew-Cree cosmology.

HOW DID ANNETTE BECOME AN ASTRONOMER AND ARTIST?

Annette has always felt a strong connection to the stars. As a member of the Lakota and Ojibwe communities, she believes that humans are made up of four things: body, mind, heart and spirit, and that the spirit is pure star energy. For as long as she can remember she has dreamt about the stars, and those dreams have led her to become both an artist and an astronomer.

Being a scientist and an artist can be difficult at university, where the two disciplines are seen as separate. Her culture, however, told her that science is rooted in the mind and body, while art is rooted in the heart and spirit. Choosing one or the other would be to neglect half of her full self. To pursue both passions, Annette did two undergraduate degrees (in mathematics and art), two master's degrees (in fine arts and astrophysics) and a PhD in astrophysics.

Annette's connection to Indigenous culture has given her a broader perspective than many astronomers, who only learn about the scientific approach. "Indigenous peoples have nurtured relationships with the stars through keen observations, place-based ceremony, navigation and celestial architecture for tens of thousands of years," she says. "The Indigenous relationship with, and knowledge of, the sky is exceptional in that it encompasses mind, body, heart and spirit."

As an astronomy professor and professional artist, Annette is committed to making astronomy more culturally diverse. In 2007, she launched Native Skywatchers as a small initiative to collect traditional knowledge in the Lakota and Ojibwe communities. Since then, it has grown into a wider effort to revitalise Indigenous star knowledge and Annette has worked with communities around the world, including in Hawai'i, Alaska, Aboriginal Australia and Māori New Zealand.

PROFESSOR ANNETTE S. LEE
Director of Native Skywatchers

Arizona State University, USA
University of Southern Queensland, Australia
University of California Santa Cruz, USA

Annette's work has been an inspiration to many. For example, the national parks in the US attract visitors looking for dark, starry skies, making them an ideal location to share traditional astronomy. The National Park Service has therefore begun working with Indigenous communities to provide cultural stargazing experiences.

NATIVE SKYWATCHERS - WE ARE STARDUST

Raja and Annette have teamed up in a collaboration called 'Native Skywatchers - We Are Stardust', to give students the opportunity to explore the scientific and cultural significance of stars. Students video-call astronomers as they make telescope observations, effectively 'eavesdropping' on a night of research at the observatory, and interview cultural experts in their own communities to learn traditional knowledge of the stars.

In 2021, Ruvarashe (Rue) Moyo and Nokutenda (Noku) Saurombe, students at Queen Elizabeth High School in Zimbabwe, took part in We Are Stardust. "I learnt that Two-Eyed Seeing is better than one," says Rue. "We Are Stardust brought together western science and Indigenous knowledge in a beautiful way," adds Noku.

"I learnt that stars are the raw materials of life," says Rue. "Everything on Earth is made of elements that were produced when stars died billions of years ago." Noku describes how "every ingredient in the human body came from elements forged by stars. The oxygen in our lungs, the carbon in our muscles, the calcium in our teeth and the iron in our blood were all created in the interiors of exploded stars."

Rue and Noku also had the opportunity to discover the significance of stars in Zimbabwean culture. "Stars are described as hope, destiny, and freedom," explains Noku, who learnt how different stars symbolise good luck, ambitions, new beginnings, and advancements in life. Rue learnt that most Zimbabwean dances and designs are inspired by the stars and their movement. "I use a small basket every day and never knew that the design on it was inspired by the Milky Way," she says.

Rue hopes to help more young Zimbabweans become curious about space and to become open-minded problem solvers. Her first priority, though, is sustainable development. "I live in a community where some people go to bed hungry and some die of curable diseases. I want to ensure basic resources are accessible to all." Noku's ambition is to become an aerospace engineer, solving the technical challenges needed to put rockets and satellites into space.

NOKUTENDA SAUROMBE AND RUVARASHE MOYO

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WHO WILL BE THE ENGINEERS OF THE FUTURE?

FOR MANY YEARS, **ENGINEERINGUK** HAS PUBLISHED DATA AND ANALYSIS OF EDUCATIONAL ROUTES INTO ENGINEERING. ITS RECENT BRIEFING FOCUSES ON THE UPTAKE OF STEM SUBJECTS IN SECONDARY SCHOOLS AND COLLEGES. SENIOR RESEARCH ANALYST **MARIE HORTON** EXPLAINS WHAT THESE DATA CAN TELL US ABOUT THE FUTURE OF ENGINEERING

WHAT IS THE PURPOSE OF THESE DATA AND ANALYSES AND WHO ARE THEY FOR?

Previously, *The State of Engineering* report was hundreds of pages long and included a detailed spreadsheet showing all the data. We understand that the way people consume this kind of information has changed and that publishing the data online is the best way to communicate these findings. We wanted to make it more user-friendly and timelier, so will be publishing a series of briefings analysing the data as they become available.

In our latest briefing, we are looking at secondary education (GCSEs and A-levels for England, Wales and Northern Ireland, and National 5s, Highers and Advanced Highers for Scotland). The data show trends in entries and pass rates and are designed for a range of audiences including educators, employers, the media and policymakers.

WHAT ARE THE DATA AND ANALYSES TELLING US?

Firstly, there are some positives for STEM subjects. Entries into GCSE single science subjects continue to rise, and maths, biology, chemistry and physics remain within the top 10 most popular A-level subjects to study, with maths being the most taken A-level subject.

However, there are far fewer girls than boys taking GCSE subjects like computing (20.7% female) and design and technology (29.2% female), and girls remain in the minority of entrants across all A-level STEM subjects, except for biology and chemistry. At A-level, there are very low numbers of girls studying some subjects such as computing, where less than 15% of the students are girls.

The number of teachers of STEM subjects in state schools in England has decreased by nearly 5% since the start of the COVID-19 pandemic. The highest teacher vacancy rates are seen in Information Technology, with 1.7 vacancies for every 100 filled roles compared to 1.1 for all subjects.

WHY IS SECONDARY EDUCATION AN IMPORTANT PIPELINE INTO ENGINEERING CAREERS?

Secondary school is a really important stage of education for future careers – if young people don't study and achieve good results in the right subjects at this stage, their subject choices going forward will be more limited and they may be less likely to consider a role in engineering.

WHICH STEM SUBJECTS FACILITATE A CAREER IN ENGINEERING?

There is a range of engineering careers that have different requirements but, in general, the major STEM subjects include biology, chemistry, physics, as well as maths, computer science, and design and technology. Most schools in the UK don't offer engineering as a subject at GCSE, so it's important that employers consider a range of relevant subjects.

WHY IS THERE A PERSISTENT UNDER-REPRESENTATION OF GIRLS IN KEY STEM SUBJECTS?

This is something we don't fully understand yet. Girls' pass rates are better than, or similar to, that of boys in all the STEM subjects at GCSE and A-level. This is, of course, not unique to STEM, so in order to increase female representation, it's important that careers in STEM and engineering become more attractive to girls.

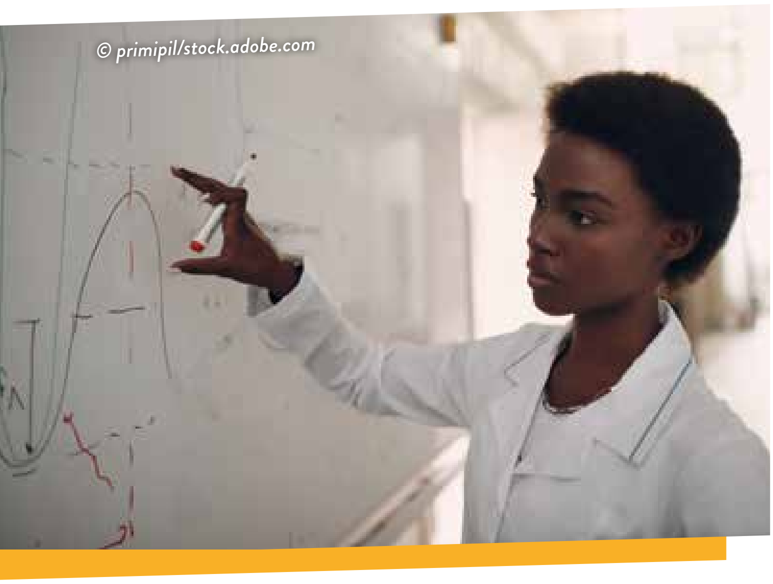
WHAT CAN WE DO TO MAKE STEM CAREERS MORE ATTRACTIVE TO GIRLS?

Employers in STEM, and engineering in particular, need to work together to publicise the range of careers available within the sector and the range of skills that can be applied in these roles.

There are inspiring women doing important and exciting things in STEM jobs. Employers need to be showcasing female role models so that girls can see themselves in a STEM or engineering career and study the required subjects to do so. Campaigns like **Tomorrow's Engineers Week** (November), International Women in Engineering Day (June) and International Day of Women and Girls in Science (Feb) are great opportunities to do this, but this can happen all year round across a range of platforms. Neon has a wide range of case studies, which you can filter by sector or route into the industry (see next page), and This is Engineering (**www.thisisengineering.org.uk**) features engineers in surprising roles.

HOW CAN WE ATTRACT MORE TEACHERS OF STEM SUBJECTS?

There are various initiatives in place to attract teachers of STEM subjects, such as bursaries. These are working for some subjects – for example, biology has exceeded targets for recruitment – but not for others. Some of these financial incentives have been increased for the next academic year with the hope that this will attract more teachers into schools.



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WHY DO WE NEED ENGINEERS?

Engineering is a very diverse field that touches our lives daily. Far from what many perceive it to be (the hard hat stereotype), engineering plays a pivotal role in driving forward products: for example, faster broadband and new digital technologies. It also plays an increasingly significant role in providing solutions to global issues such as climate change and achieving net zero. The skills needed for engineering are evolving as the needs for products and solutions change, and there is significant demand for more engineers in the future, making it an exciting career prospect.

WHAT RESOURCES DOES ENGINEERINGUK OFFER TEACHERS AND STUDENTS?

Access to clear, up-to-date and engaging careers information is important to help young people understand the breadth and relevance of a career in modern engineering, as well as navigate the various educational and vocational routes into the sector. It can also help to dispel myths and inspire students who may be thinking that engineering is not for them. One of the ways EngineeringUK does this is through its Neon platform, which helps primary and secondary school teachers introduce their students to future STEM careers, raise their aspirations and explore the excitement of engineering. The platform includes bookable experiences, video case studies and careers resources.

For more than 20 years, EngineeringUK has undertaken comprehensive research into the state of engineering in the UK – providing a detailed examination of engineering's economic contribution and the composition of its workforce, as well as the extent to which the supply through education and training pathways is likely to meet future needs and demand for engineering skills. This flagship research, once produced as a single report, is now available in a range of formats, providing the most up-to-date analysis:

www.engineeringuk.com/research

MEET MARIE

Senior Research Analyst, EngineeringUK

Marie studied mathematics with Spanish at the University of Greenwich in London, UK. She went on to study for an MSc in Applied Statistics at Birkbeck University.

WHO OR WHAT INSPIRED YOU TO STUDY MATHS?

I always enjoyed maths as a subject at school. I like the fact that it has processes to follow, and you get a clear answer at the end of your calculations, rather than responses being open to interpretation, as in other subjects.

WHY DID YOU DECIDE TO STUDY SPANISH, TOO?

I studied Spanish at A-level because I knew that I wanted to travel to Central America after finishing my degree. By including a language as part of my degree, it gave some variation to what I was studying but also enabled me to develop some additional skills.

WHAT WAS YOUR AIM IN STUDYING FOR AN MSC IN APPLIED STATISTICS?

My degree in maths covered a broad range of topics and through this I realised that I wanted statistics to be my speciality. I was lucky enough to be able to study for my master's at Birkbeck University in the evenings whilst also working as an analyst, and once I received my qualification, I was then able to further my career in statistics.

WHAT DOES YOUR ROLE AS SENIOR RESEARCH ANALYST ENTAIL?

I work mostly with survey data, analysing datasets and producing reports and briefings showing the latest results and trends. At EngineeringUK, we run our own surveys, such as the **Engineering Brand Monitor**, where we ask young people, parents and teachers about their knowledge of, and interest in, engineering as a career. We also use some larger datasets from the Office for National Statistics to look at who is working in engineering, the types of jobs they're working in, and how this is changing over time. As Senior Research Analyst, I'm looking to provide insights for the engineering sector, answering questions and advising policy colleagues on questions such as: are there particular engineering careers that attract women?, how popular are different routes into an engineering career?, how much do people know about what engineers do?

WHAT DO YOU LOVE MOST ABOUT YOUR JOB?

I enjoy digging into the data and exploring what people are telling us through the survey responses. I also like being able to present

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> “
> LOOK AT ALL THE ROUTES INTO DIFFERENT CAREER PATHS. UNIVERSITY IS NOT THE ONLY WAY TO GET INTO ENGINEERING; THERE ARE MANY VOCATIONAL ROUTES SUCH AS T-LEVELS AND APPRENTICESHIPS THAT WILL ALSO ALLOW YOU TO PROGRESS TO A SUCCESSFUL CAREER.
> ”

these findings to a variety of audiences so that they can use them as an evidence base to make changes in the way things happen in the workplace. It shows the power that data can have to facilitate improvements and reduce inequalities.

WHAT ARE YOUR TOP TIPS FOR YOUNG PEOPLE CHOOSING SUBJECTS AT COLLEGE AND/OR UNIVERSITY LEVEL?

Look at all the routes into different career paths. University is not the only way to get into engineering; there are many vocational routes such as T-levels and apprenticeships that will also allow you to progress to a successful career.

If you're interested in a particular career, make sure you do your research about the requirements for entry, so that you study the correct subjects to allow you to progress.

If you're not sure what you want to do, study something that you enjoy and that will allow you to have a range of options as you achieve your A-levels and further education qualifications.

NEON RESOURCES

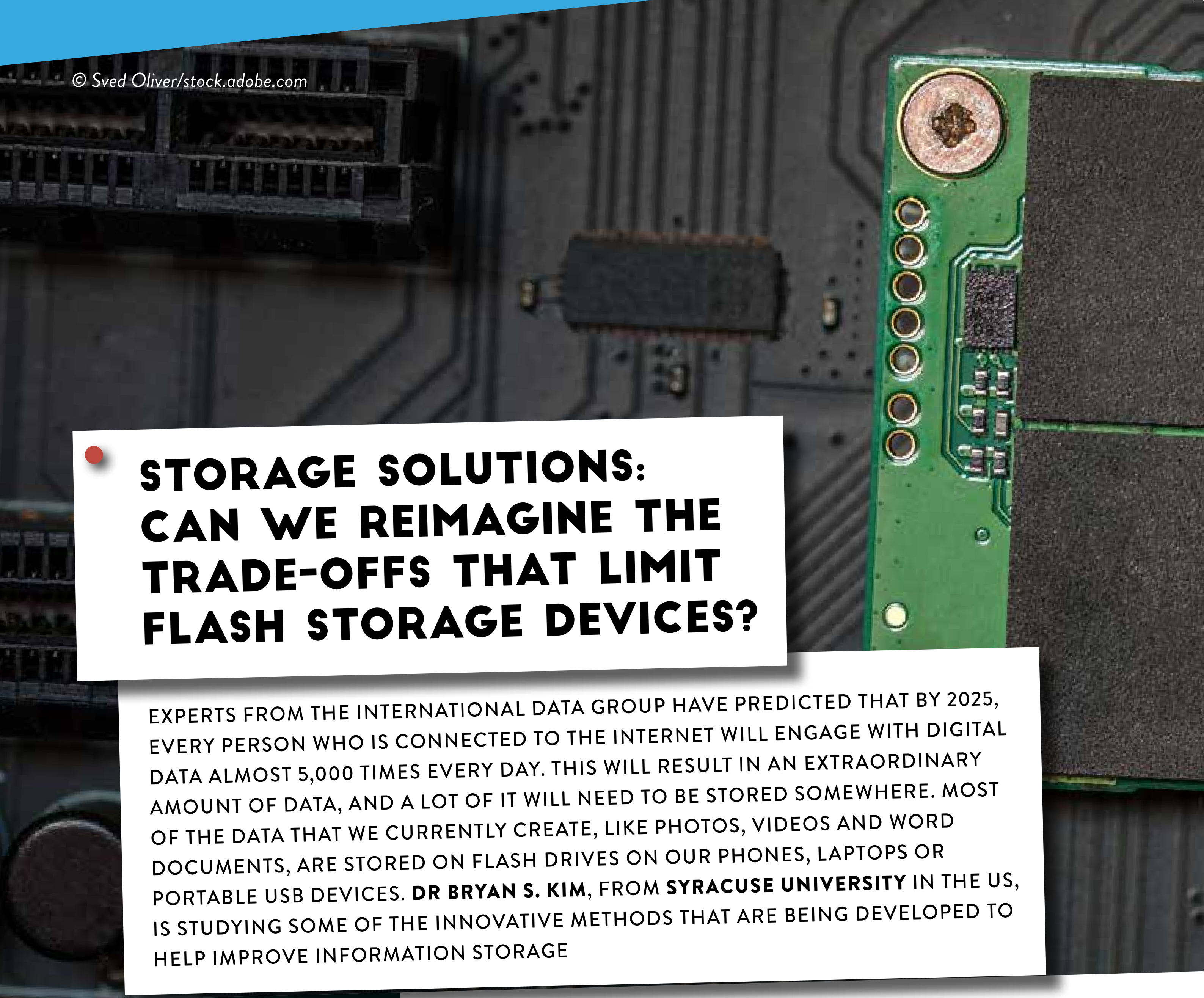
neonfutures.org.uk

Bookable STEM and engineering experiences – searchable by postcode, STEM and engineering experiences range from activities that teachers can deliver in the classroom, and take under an hour to do, to whole-day, off-site experiences.

Engineer case studies – a growing collection of case studies showcasing the different types of, and routes into, engineering.

Careers resources – leaflets, posters, postcards, guides, presentations and quizzes about careers in engineering. Popular resources include 'Meet the future you' – a fun online quiz that helps students connect their passions and skills with different careers in engineering. There is a set of four classroom display posters showing how engineers are at the forefront of helping the UK reach its net zero target. There is also a useful PowerPoint presentation – 'Engineer your future' – designed for teachers and careers advisers to help students understand more about the opportunities presented by a career in engineering.

These resources are available to download or order in print from Neon free of charge. The resources are developed by EngineeringUK's Careers Working Group, a collaborative group drawn from across the engineering community, and are created in consultation with teachers and students.



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STORAGE SOLUTIONS: CAN WE REIMAGINE THE TRADE-OFFS THAT LIMIT FLASH STORAGE DEVICES?

EXPERTS FROM THE INTERNATIONAL DATA GROUP HAVE PREDICTED THAT BY 2025, EVERY PERSON WHO IS CONNECTED TO THE INTERNET WILL ENGAGE WITH DIGITAL DATA ALMOST 5,000 TIMES EVERY DAY. THIS WILL RESULT IN AN EXTRAORDINARY AMOUNT OF DATA, AND A LOT OF IT WILL NEED TO BE STORED SOMEWHERE. MOST OF THE DATA THAT WE CURRENTLY CREATE, LIKE PHOTOS, VIDEOS AND WORD DOCUMENTS, ARE STORED ON FLASH DRIVES ON OUR PHONES, LAPTOPS OR PORTABLE USB DEVICES. **DR BRYAN S. KIM**, FROM **SYRACUSE UNIVERSITY** IN THE US, IS STUDYING SOME OF THE INNOVATIVE METHODS THAT ARE BEING DEVELOPED TO HELP IMPROVE INFORMATION STORAGE

TALK LIKE A COMPUTER ENGINEER

SOLID-STATE DRIVES (SSDs) – a storage device that uses electronically programmable flash memory to store data. They are the *de facto* storage for mobile systems

HARD DISK DRIVES (HDDs) – a storage device that uses magnetic and mechanical components to store data. They are bulkier, slower and more power-intensive than SSDs

CAPACITY – the amount of data that can be stored on a storage device

RELIABILITY – the ability to maintain the original data without errors or corruption

PERFORMANCE – the speed at which data in a storage device can be accessed (latency) or how much data can be accessed in a given time (throughput)

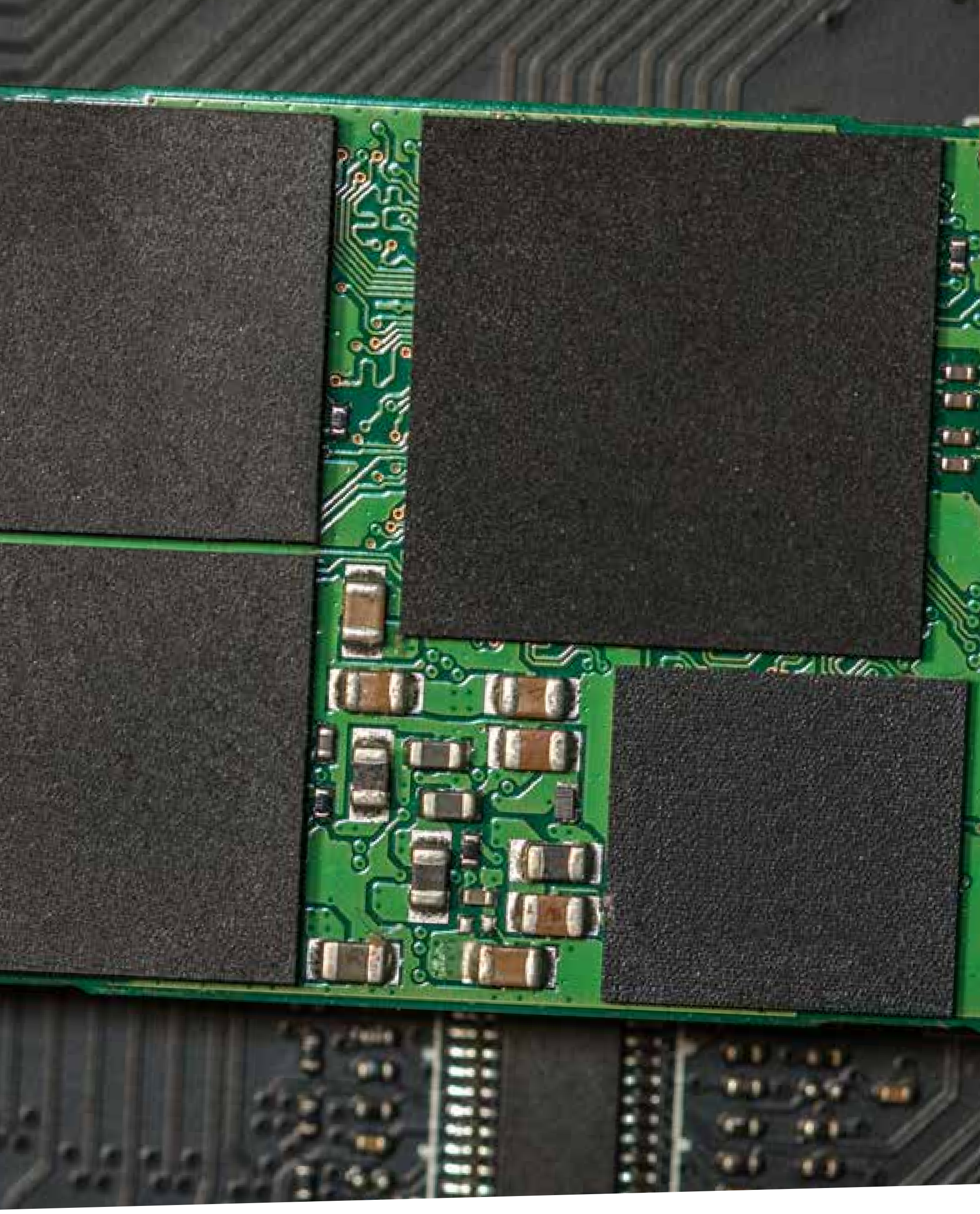
In today's technology-driven world, the amount of data that each of us generates is increasing rapidly. Every photo you take on your phone, every save you make in a video game and every word document you create for school needs to be stored somewhere. The chances are that most of your devices make use of something called flash storage to store all your data.

Flash storage, also known as solid-state drives (SSDs), is a type of electronic data storage that keeps its data persistently. This means that when you turn the storage device off and back on again, all the data will still be there. These days, SSDs are everywhere, from USB sticks and smartphones to PCs and large-scale cloud systems.

SSDs are so popular due to their advantages over the more traditional hard-disk drives (HDDs). HDDs store data using a mix of magnetic and mechanical parts, making them bulkier and susceptible to damage from vibrations and other physical disturbances like being dropped. SSDs, on the other hand, are completely electronic, allow computers and devices faster access to information stored in them and consume less power than HDDs.

The one advantage that HDDs have over SSDs is their price. In terms of cost per byte, SSDs are more expensive than HDDs. However, there is a huge amount of effort being focused on how to increase the density of SSDs to reduce their cost. Many of these techniques involve making trade-offs between three aspects of data storage: capacity (cost per byte), reliability (error rate) and performance (how fast data can be accessed).

Finding the best way to balance these trade-offs is a complex problem that many scientists and engineers are trying to solve. One such researcher is Dr Bryan S. Kim, an assistant professor at the College of Engineering and Computer Science at Syracuse University in the US. Bryan has been researching flash storage systems to discover innovative methods that might improve their efficiency.



BRYAN S. KIM

Syracuse University, USA

FIELD OF RESEARCH

Computer Engineering

RESEARCH PROJECT

Exploring better ways to build data storage systems to balance the trade-off between capacity, reliability and performance

FUNDER

US National Science Foundation (NSF)

This material is based on work supported by the NSF under Grant CNS-2008453. Any opinions, findings, conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the NSF.

WHAT TECHNIQUES ARE USED TO INCREASE SSD DENSITY AND REDUCE ERROR RATES?

Storage density is a measure of how many 'bits' of data can be stored in a device. A bit represents a single binary data point (1 or 0) and is the most basic unit of information in computing. "The techniques for increasing the density of SSDs include packing more bits into a smaller cell or stacking cells on top of each other vertically," says Bryan. "However, these, in turn, increase the error rate of the storage."

There are a few different techniques that SSDs use to reduce their error rate and increase their reliability. "The first line of defence against errors are error correction codes (ECCs)," explains Bryan. ECCs can detect errors in the original code and correct them, but they only have a limited number of errors that they can correct. If the ECC fails, then the SSD may attempt to re-read the data using a different set of parameters. Some SSDs even proactively read the data stored on them and make corrections before the data become corrupted.

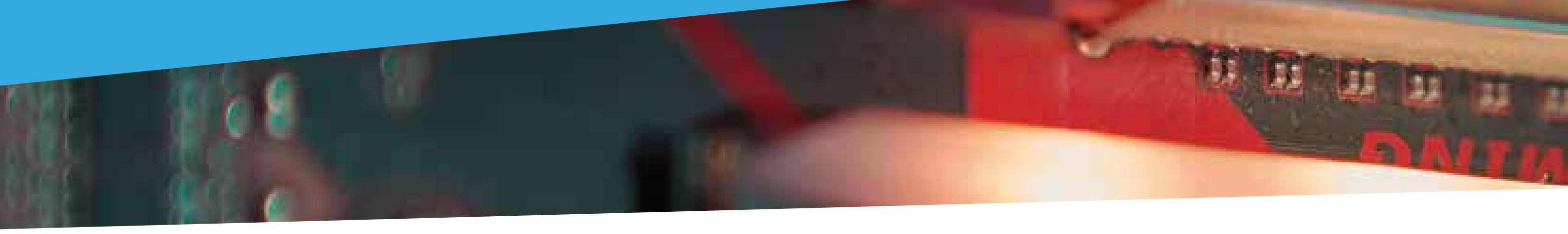
Unfortunately, these techniques, which are designed to increase reliability, have a detrimental effect on the performance of the system. Here, we can see how the trade-off between capacity, reliability and performance works: engineers attempt to increase the capacity of SSDs, which reduces the reliability of the storage drives. And when engineers attempt to increase the drive's reliability, its performance is reduced, which can lead to fail-slow symptoms.

WHAT ARE FAIL-SLOW SYMPTOMS AND HOW CAN THEY BE AVOIDED?

As the components of a storage system age, wear out and begin to fail, the performance of the storage system will get worse. This decreased level of performance can result in stalling, glitches and slower processing speeds, all of which are examples of fail-slow symptoms. The storage units within an SSD, known as cells, wear out over time and become more error prone. This deterioration causes the performance to slow down as the system puts more effort into reducing errors and maintaining its capacity.

Bryan's research suggests that a concept known as capacity variance may provide a solution to the problem of fail-slow symptoms. Most storage drives currently have a fixed capacity. "For example, a new 1 terabyte (TB – 1,000 gigabytes) SSD will always be 1 TB in total size," says Bryan. "To maintain the illusion of a 1 TB-sized healthy set of blocks, the device internally uses reliability enhancement techniques that sacrifice performance, leading to fail-slow symptoms."

Bryan argues that a storage system with the ability to vary its capacity could be more effective. A capacity-variant storage system would be able to reduce its capacity as its cells begin to deteriorate and fail. "For example," explains Bryan, "a 1 TB SSD may reduce its capacity to 900 GB when some of its cells degrade and exhibit higher error rates." Removing worn-out cells would get rid of the need to perform reliability-enhancing techniques. This would allow the system to maintain its performance and avoid developing fail-slow symptoms. "Essentially," says



Bryan, “the fixed-capacity model sacrifices performance to maintain capacity and reliability.” However, a capacity-variant model would allow a system to sacrifice capacity to maintain performance and reliability.

WHAT ARE THE CHALLENGES BRYAN FACES WHEN UNDERTAKING THIS RESEARCH?

The deterioration of SSDs occurs over an extended period as errors accumulate. The errors that cause this deterioration occur by chance and are therefore difficult to predict. This makes studying fail-slow symptoms challenging because it is hard to accurately re-create the scenarios in which they occur.

When studying SSDs by reproducing these states, Bryan must contend with another trade-off. “That is,” Bryan explains, “we can either age an SSD quickly while sacrificing how realistic the aging process would be, or we can age it slowly while being close to how it would really behave.” Bryan is hoping to bypass this problem by creating a data-driven model that learns how SSDs deteriorate based on past occurrences.

WHAT HAS BRYAN’S RESEARCH UNCOVERED SO FAR?

As a precursor to the idea of capacity variance, Bryan and his team have been arguing against the effectiveness of some reliability-enhancing techniques. One such technique is known as wear levelling. This involves spreading the deterioration of cells equally around the storage system. “It makes sense to do this if we would like the SSD to exhibit an all-or-nothing failure state,” says Bryan. “Either all of its cells are worn out and unusable, or none of them is.”

With a capacity-variant system, wear levelling would no longer be necessary. Bryan and his team have collected and analysed lots of data that highlight the problems with wear levelling, which they hope will strengthen their argument for capacity-variant systems.

WHAT ARE THE NEXT STEPS FOR BRYAN’S RESEARCH?

“Our research group is always thinking about exploring better ways to build storage systems,” says Bryan. A lot of the time, this involves making sure that a system is using the right kind of interface. Most storage systems use a fixed capacity interface; however, as we have seen, these are not always the most effective. Aside from their capacity-variant concept, Bryan and his team are excited by two other kinds of interfaces.

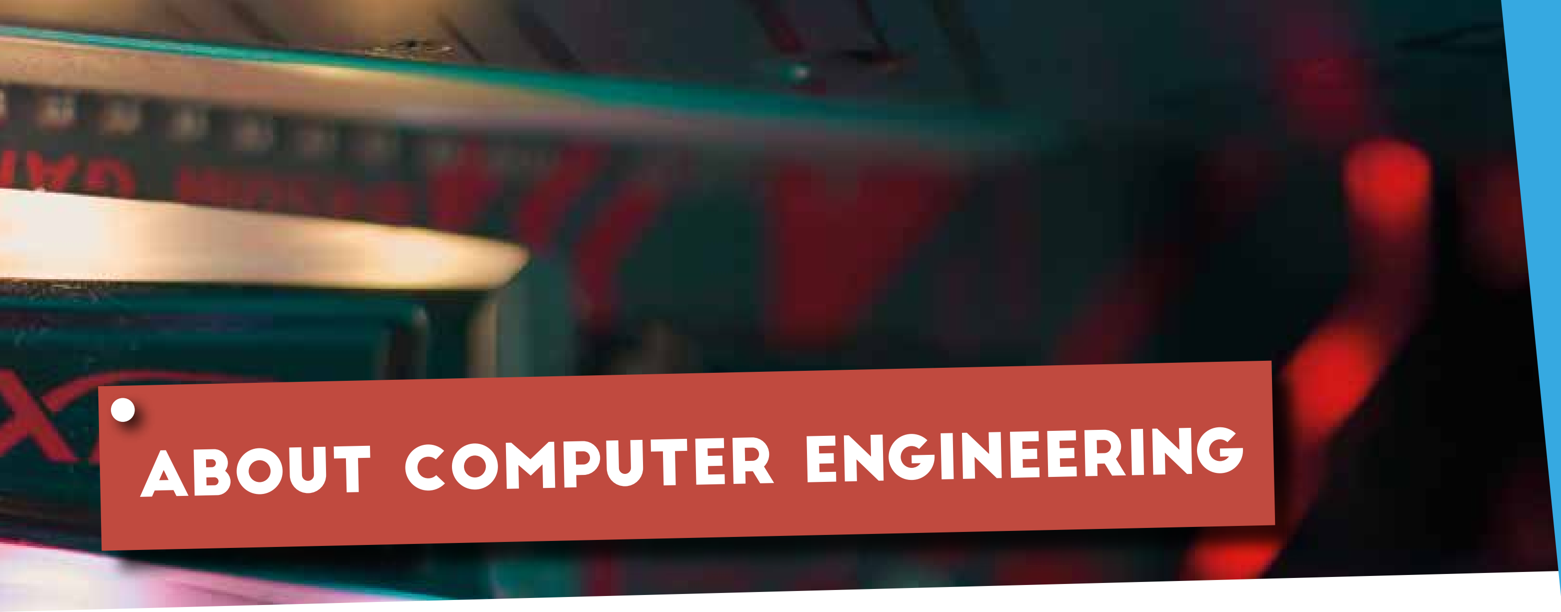
The zoned namespace (ZNS) interface allows incoming data to be grouped based on their use and how often the information needs to be accessed. This allows the design of the SSD to be simplified and increases its efficiency and longevity. Bryan also emphasises his enthusiasm for another kind of interface known as a key-value (KV) interface. Key-value interfaces make SSDs more complex, but significantly increase the processing power of the system. “Again, there exists a set of trade-offs,” says Bryan. “We can’t have it all!

PATHWAY FROM SCHOOL TO COMPUTER ENGINEERING

- Studying maths at school is fundamental and is an entry requirement for most computer engineering courses. Taking classes in physics and IT (if they are offered) will also provide you with a good foundation.
- Studying these subjects should help you get a place on a computer engineering degree at university, which is vital if you want to be a computer engineer. There are many different courses to choose from, so make sure to do your research.
- Join your school’s computing club. This is a wonderful way to get hands-on experience with computers and make some new friends.
- Consider going to a computer science summer school (e.g., **www.summerschoolsineurope.eu/search/discipline;comsc**). This is an interesting way to gain experience and will look great on your university application.

EXPLORE CAREERS IN COMPUTER ENGINEERING

- The Association for Computing Machinery (**www.acm.org**) has many resources and general material that may be of interest to anyone thinking about a career in computer engineering.
- USENIX (**www.usenix.org**) is another society that provides resources and support for people who are interested in computer engineering. They also have a discounted student membership.
- The Charted Institute for IT (**www.bcs.org**) has lots of resources for people exploring a career in computer engineering. It also runs an apprenticeship programme to help young people start a career in the industry.
- According to Salary.com, the average salary for a computer engineer in the US is $89,000 (**www.salary.com/research/salary/listing/computer-engineer-salary**)



ABOUT COMPUTER ENGINEERING

Computer engineering is a field that combines electrical engineering and computer science. Computer engineers design and develop hardware and software that is used in all kinds of computing contexts, from laptops and supercomputers to self-driving cars and robots.

> **"IDEAS ARE NEVER STUCK AT THE 'ON THEORY' OR 'ON PAPER' STAGE, BUT ARE ALWAYS IMPLEMENTED AND EVALUATED TO SEE HOW THE IDEAS WOULD FARE IN THE REAL WORLD."**

The demand for computer engineers is expected to continue increasing over the next decade. Computers and computer-based systems play a huge role in our lives, and that does not look like it will be changing any time soon.

WHAT IS REWARDING ABOUT A CAREER IN COMPUTER ENGINEERING?

"Computer systems research tends to be practical and hands-on with a lot of real-world impact," says Bryan. "Ideas are never stuck at the 'on theory' or 'on paper' stage but are always implemented and evaluated to see how the ideas would fare in the real world."

Computer engineers are often involved in developing cutting-edge technology. "We are at the forefront of the industrial revolution," says Bryan. Computer engineering is an exciting field to be a part of because new, innovative technologies are being created all the time. As we advance further into the 21st century, our need for technological innovation is only going to increase.

WHAT SKILLS AND PERSONAL QUALITIES ARE USEFUL FOR COMPUTER ENGINEERS TO HAVE?

Curiosity is an excellent quality to have as it drives you to learn more and understand the inner workings of many different devices and things. Abstract reasoning is also another excellent quality because it helps you put those tiny details from your curiosity into the big picture; the two qualities should go together.

HOW DID BRYAN BECOME A COMPUTER ENGINEER?

WHAT WERE YOUR INTERESTS WHEN YOU WERE YOUNGER? HAVE YOU ALWAYS BEEN FASCINATED BY ENGINEERING AND COMPUTER SCIENCE?

I enjoyed playing and building with Lego as a child and have always been interested in math. Up until when I was applying for college, I actually did not think that engineering and computer science would be the path that I would be taking – in fact, a lot of my high school friends thought I would major in math. I sent out a mix of college applications and chose to go in the direction of engineering and computer science.

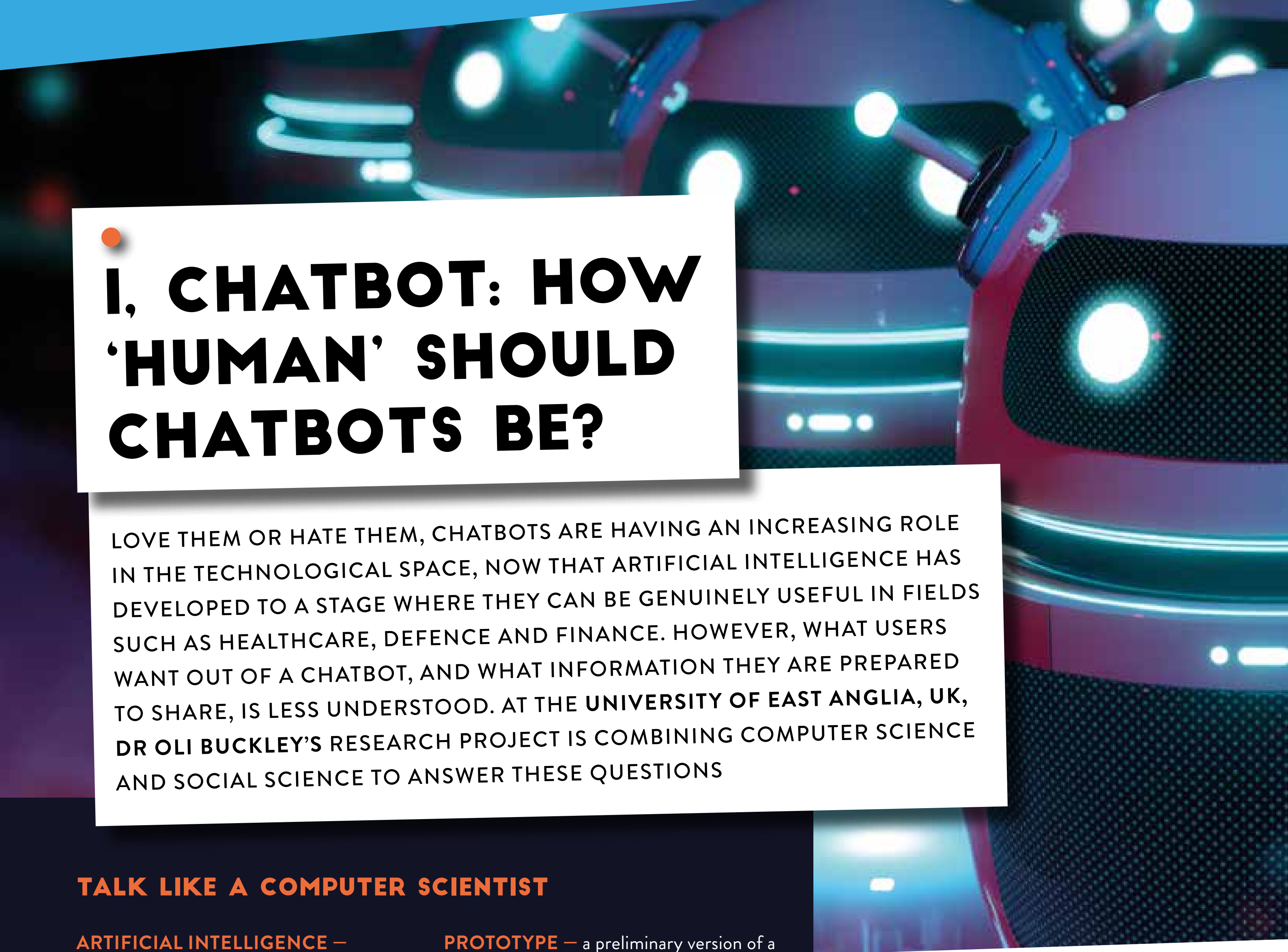
I did not do very well in college, however. Most (if not all) other students had experience with programming and computer science coming into college while I had none, and everyone seemed smarter than me.

WHAT DO YOU ENJOY DOING WHEN NOT WORKING?

While my toddler is awake, I enjoy playing and spending time with him. When he is asleep (and finally peaceful), my wife and I like to play board games together.

BRYAN'S TOP TIPS

1. Tinker with stuff. Build stuff, find ways to improve, tear it down and make it better.
2. Manage your time well. Don't miss deadlines but spend time on what is important to you.
3. Develop your logical thinking. It is fundamental for computer engineering.



I, CHATBOT: HOW 'HUMAN' SHOULD CHATBOTS BE?

LOVE THEM OR HATE THEM, CHATBOTS ARE HAVING AN INCREASING ROLE IN THE TECHNOLOGICAL SPACE, NOW THAT ARTIFICIAL INTELLIGENCE HAS DEVELOPED TO A STAGE WHERE THEY CAN BE GENUINELY USEFUL IN FIELDS SUCH AS HEALTHCARE, DEFENCE AND FINANCE. HOWEVER, WHAT USERS WANT OUT OF A CHATBOT, AND WHAT INFORMATION THEY ARE PREPARED TO SHARE, IS LESS UNDERSTOOD. AT THE **UNIVERSITY OF EAST ANGLIA, UK, DR OLI BUCKLEY'S** RESEARCH PROJECT IS COMBINING COMPUTER SCIENCE AND SOCIAL SCIENCE TO ANSWER THESE QUESTIONS

TALK LIKE A COMPUTER SCIENTIST

ARTIFICIAL INTELLIGENCE — computer systems able to perform tasks normally requiring human intelligence

CYBER SECURITY — the application of technology to protect online spaces and data from cyberattacks

DEMOGRAPHIC — attributes of those within a population, such as age, ethnicity or height

PROTOTYPE — a preliminary version of a particular tool

WIZARD-OF-OZ EXPERIMENT — a particular form of an experiment in which participants believe they are communicating with a computer, but are interacting with a human

CHATBOT — a computer program that simulates conversations with human users

Services such as healthcare and finance are increasingly integrating intelligent technology, to take the pressure off people in the sector and to help ensure that users are given the best service possible. Dr Oli Buckley is leading a project called the Platform for Responsive Conversational Agents to Enhance Engagement and Disclosure (PRoCEED). This project aims to optimise chatbot technology for individuals and increase the trust needed for the conversations that ensue to help the user. Oli and his team are based at the University of East Anglia, while other project research partners are from the University of Cranfield, the University of Kent and Oxford Brookes University.

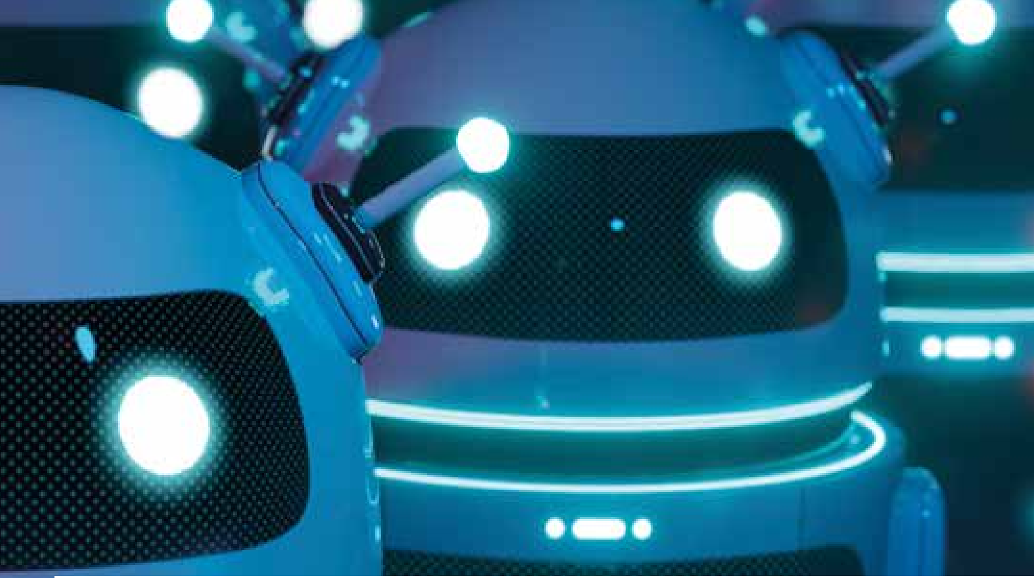
A 'chatbot' is any computer program that simulates a conversation with human users. They are typically used on a wide variety of websites to help guide users to the resources most relevant to them. "Chatbots can be found on pretty much every major website or service now," says Oli. "What interests me personally is that it can be difficult to tell whether you're talking to a real person or a computer, and I'm curious about how that uncertainty affects the way someone might communicate."

This is often the case with technological advances: while capabilities increase dramatically, understanding the way that people make use of these capabilities tends to lag. "Although the technology is readily available for chatbots to fairly convincingly pass as humans during conversations with users, whether users want this is less understood," says Oli. "Our work aims to help service providers understand how this technology can best be applied to ensure users feel most comfortable."

TAILORING THE ONLINE WORLD

"As the world has become accustomed to working online and interacting with online services, we have become used to typing messages and chatting online," says Oli. "Most people do this every day via messaging apps or texts, and so it is a familiar way of communicating." Chatbots utilise this method, asking specific questions of users and responding accordingly to their answers.

"Chatbots can be customised based on user preference, and this is the heart of our research," says Oli. "We want to understand whether different groups of people feel more comfortable with different types of bots. For example, do some people want to feel like they're talking to a human or do some prefer talking to something obviously robotic?"



DR OLI BUCKLEY

Associate Professor in Cyber Security
School of Computing Sciences,
University of East Anglia, UK

FIELDS OF RESEARCH

Computer Ccience, Cyber Security

RESEARCH PROJECT

Investigating how chatbot technology can be optimised to provide a more effective method of communication, especially regarding building trust with the user

FUNDER

Engineering and Physical Sciences Research Council (EPSRC)

Answering these questions is very important for sectors such as healthcare, where making sure people feel comfortable enough to be honest and share potentially sensitive information is vital to ensuring they get the care they need. "The pandemic emphasised the need for this technology, as activities increasingly moved online and as healthcare services became increasingly under pressure," says Oli. "Chatbots can enable large numbers of users to be assessed to discern who is in the greatest need."

THE PROCEED PROJECT

"We used lots of different methods for this project," says Oli. "One of the most significant was a 'Wizard-of-Oz' experiment, in which participants believe they are talking to a chatbot but are actually conversing with a researcher." The team used this technique to ensure they could give consistent responses to users' questions, while users' answers reflected the ways they would converse with real chatbots.

This inclusion of human participants was essential for determining optimal human-chatbot interactions. "Humans are fascinating and always seem to respond differently to how you might expect," says Oli. "Understanding what works for people and what doesn't was a big challenge for our research, but an enjoyable one to tackle." In addition to experiments, the team studied existing academic literature on the subject, to make sure their work built on what had already been done.

SENSITIVE INFORMATION

Oli's team wanted to understand how comfortable people were with sharing different types of sensitive information with a computer. "We found that several factors impacted how people disclosed information," says Oli. "These factors included risk of harm, trust in the method of interaction, public availability of the data, context of the data and risk of re-identification." People also indicated concerns about sharing data related to personal safety, mental health or consequences for loved ones.

"We ranked data in terms of sensitivity based on user responses," says Oli. "We found that passwords were considered the most sensitive, followed by bank account details and other financial data. The least sensitive included things that are usually observable, such as height, weight, gender and hair colour." Context and individual experiences also had an important role to play in the willingness to share certain types of information. Understanding these perceived sensitivities is useful for understanding what types of chatbots might be most appropriate in different scenarios.

CHATBOTS OR HUMANS

The team found that context was very important in terms of people's preferences regarding talking with chatbots or humans. "People generally preferred to talk to other humans, particularly about health matters," explains Oli. "This preference was less pronounced for financial matters, such as sharing credit scores or income levels."

Preferences also depended on the demographics of the people involved. "We used the Wizard-of-Oz approach to gauge how much a person's characteristics affected how they engaged with different sorts of chatbots – human-like, machine-like or between the two," says Oli. These results are still being evaluated but have the potential to help tailor chatbots to people's needs.

The team found that the way users interacted with computers, such as how they typed or used a computer mouse, was often linked to individual traits such as age and gender. "Computers can use these clues to guess an operator's demographic so that the chatbot best suited to them can be automatically selected and used," says Oli.

NEXT STEPS

Currently, the team is aiming to develop a prototype system of the technologies they investigated, which will deploy the appropriate chatbot for a user based on their probable preferences, which can be inferred from the way they use a computer. "We are also developing a tabletop game based around information sharing with machines," says Oli. "This should help people understand the benefits and risks associated with sharing information with a chatbot, or any machine."

The team's findings are also directly informing new research projects. "I'm currently using our findings to see how chatbots can be used in mental health settings," reveals Oli. "I've also recently started a project exploring the use of chatbots to encourage healthcare patients to log symptoms and daily updates to give a more rounded overview of their condition." Healthcare, in particular, will benefit a lot from more customised chatbots, which have the potential to address several of the challenges encountered by health services around the world.

ABOUT COMPUTER SCIENCE

Computers are everywhere in the modern world and will become even more integrated into our lives in the future. Computer science as a discipline is becoming increasingly broad, ranging from 'traditional' computer science careers that focus on programming and coding, to social research into how computers can help solve societal problems. Oli explains more about his career and how the field is set to change in the future.

I like the varied challenges of cyber security research, particularly investigating how people interact with technology. At this point in my career, I rarely write code. I think working across different disciplines and constantly learning about new ideas is fantastic, as is being able to work with people. The people who take the time to program and write the codes are far more interesting than the software itself!

Being able to communicate your ideas and work to a non-technical audience is just as valuable as writing code – if not more so. Computer science is so much more than just coding. There are a whole host of areas you can work in, even if you don't want to write code for the rest of your life.

Technology is now reaching a point where it can realistically do the things I considered futuristic sci-fi material when I was younger. This means that the way people use technology is becoming even more interesting. The human aspect plays an important role in things, and we need to explore this.

As artificial intelligence continues to develop, we'll increasingly see the technology in even more places. Understanding how it fits alongside ethical and social implications is very important. For example, a computer may 'intelligently' rank people on a hospital waiting list, but is it ethically logical and reasonable? Does it consider unmeasurable emotional aspects, for instance?

Technology is now so readily available, with most of us carrying immensely powerful computers in our pockets. This means that more people have access to the internet, social media and online games, all of which involve sharing data. This poses important questions around security, privacy and trust, as well as the psychological and developmental implications of lives spent online. It will be interesting to see how future 'internet-native' generations evolve with technology and what challenges arise for computer scientists.

EXPLORE CAREERS IN COMPUTER SCIENCE

- Oli recommends sites such as Code Academy as an introduction to learning to code, which is an important skill for most computer science careers: **www.codecademy.com**
- The University of East Anglia's School of Computing Sciences (**www.uea.ac.uk/about/school-of-computing-sciences**), where Oli works, has regular events with local schools as well as online outreach events. They often have a strong presence at the Norwich Science Festival (**norwichsciencefestival.co.uk**) and offer work experience and internship opportunities.
- Computer scientists are in high demand. According to Check-a-Salary, the average annual salary for computer scientists in England is £42,000.

PATHWAY FROM SCHOOL TO COMPUTER SCIENCE

Although mathematics and computing ability are essential, Oli believes that a wide range of skills is important for a modern-day career in computer science.

He recommends subjects such as psychology to understand how people use technology, as well as communication skills. "Being able to write coherently about a subject is a hugely underrated skill in computer science at present," he says.

HOW DID OLI BECOME A COMPUTER SCIENTIST?

WHAT WERE YOUR INTERESTS GROWING UP?

When I was younger, I wanted to be an artist because I loved drawing and creating things. I later aspired to become a doctor, until I realised that I couldn't stand the sight of blood. I was always interested in computers and technology, but never really considered it as a career until much later.

WHAT ATTRIBUTES HAVE HELPED MAKE YOU SUCCESSFUL?

Although I have worked as a software engineer and did a reasonable job, I'm not the greatest programmer and didn't have the patience to spend hours debugging code. I think my biggest strength is that I'm comfortable talking to people and enjoy explaining my ideas in an accessible way. I break the stereotype of the unsociable, disengaged computer scientist, as I love presenting my work and talking about my ideas. Users are fascinating, not an inconvenience, as some programmers believe.

HOW DO YOU OVERCOME OBSTACLES IN YOUR WORK?

I'm a firm believer in mindfulness. There is a lot going on in modern life and it is easy to become overwhelmed. Taking a moment to be in the present is massively useful when it comes to reframing a problem. Some of my solutions come to me when I'm not thinking about the problem.

I BREAK THE STEREOTYPE OF THE UNSOCIABLE, DISENGAGED COMPUTER SCIENTIST, AS I LOVE PRESENTING MY WORK AND TALKING ABOUT MY IDEAS.

HOW DO YOU SWITCH OFF FROM WORK?

I like to run regularly, accompanied by an audiobook. I don't have a competitive streak; I just use it as an escape and like the peacefulness. I also love to play computer games, although being a father of four means there is little time to do this! I've slowly expanded that passion to include board games so that we can all sit and play as a family.

WHAT ARE YOUR PROUDEST CAREER ACHIEVEMENTS SO FAR?

After my PhD, I was quite disillusioned with scientific research. After a break, I came back to it and found a different field that I actually enjoyed. I've since built a Master of Science course for Cyber Security and won over £2 million in research grants. I feel very lucky to dto be doing something that I enjoy, and where I am contributing to the wider world.

OLI'S TOP TIP

Be curious and take the initiative. There are thousands of resources to help you learn the technical skills needed for computer science. For instance, you can create simple games using Scratch (**scratch.mit.edu**) or build your own websites using any of several different platforms.

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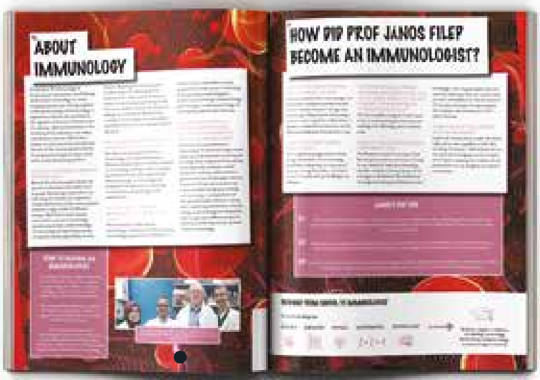

Find out how the researchers got to be where they are today

For example, János wasn't massively interested in biology when he was younger. He is now an immunologist!

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