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A SCIENCE, RESEARCH AND TECH MAG
FOR THE NEXT GENERATION

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HOW TO BUILD A STEAM GENERATION

"IF LEGO CAN TAKE ME DOWN A PATH OF SUCCESS, IMAGINE WHAT STEAM COULD DO FOR YOU!"
DAVID AGUILAR AMPHOUX, AKA HAND SOLO

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"FOLLOW YOUR BLISS."
PROF TOM BANIA AND OTHER RESEARCHERS OFFER THEIR EXPERIENCE AND TOP TIPS FOR GETTING INTO STEAM

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"IF LEGO CAN TAKE ME DOWN A PATH OF SUCCESS, IMAGINE WHAT STEAM COULD DO FOR YOU!"

An enjoyable part of my job entails proofreading the articles in this issue, the principal aim being to look out for typos and inconsistencies. But often, while reading these research stories, my focus starts to wander away from SPAG (spelling, punctuation and grammar) to imagining a career in STEAM.

Sometimes, my imagination draws on my interests as a child (the idea of volcanoes, earthquakes and glaciers shaping the Earth fascinated me at secondary school – p38); at other times, my imagination is fired up by careers I would never have considered or known about when I was younger (humanitarian engineering – p22, ergonomics – p26, or mapping the Milky Way – p50).

David Aguilar Amphoux's interview is one such article that had me browsing part-time degree courses in bioengineering – it turns out there are quite a few universities in the UK and elsewhere in the world offering this degree programme.

David's passion for helping people with disabilities, through bioengineering, is truly inspirational; and his honesty and resilience can only serve to help young people who may be facing physical or mental challenges at school or in their home lives.

Similarly, Tom Bailey's article on theatre-making for the FAMOS (From Arc Magmas to Ores) project shows us that the arts are very much an important part of STEAM. Progress in the sciences would not happen without creativity, curiosity and communication, but how many students know this?

Of course, I love my job and my flights of fancy are only fleeting, but I do know that the articles in this issue will help fire up your students' imagination and steer them on a course to a lifelong interest and career in STEAM. As Boston University's Prof Tom Bania says, let's help young people 'find their bliss'.

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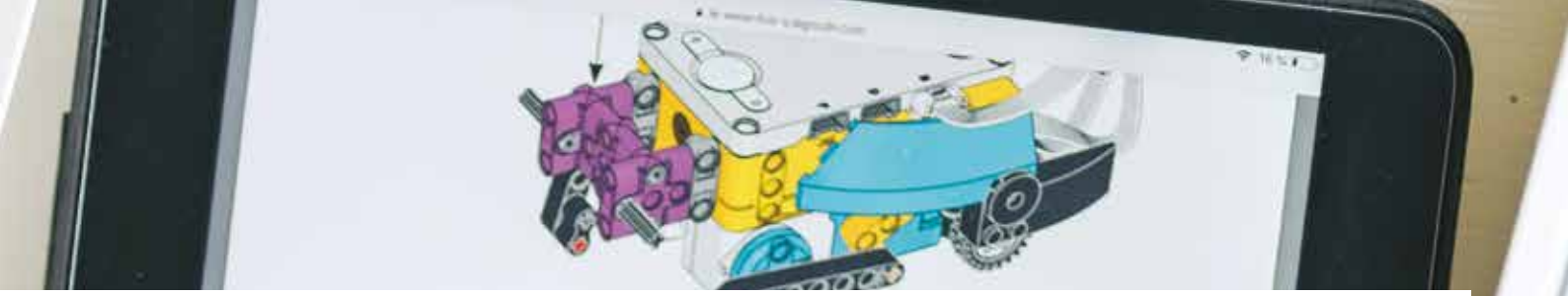

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HOW LEGO EDUCATION BECAME PIONEERS OF STEAM LEARNING

SINCE ITS LAUNCH IN 1980, **LEGO EDUCATION** HAS BEEN LOOKING FOR WAYS TO HELP STUDENTS BUILD CONFIDENCE AND OTHER SKILLSETS TO HELP THEM SUCCEED IN SCHOOL AND BEYOND. **DR JENNY NASH**, HEAD OF EDUCATION IMPACT IN THE US, REFLECTS ON HOW LEGO EDUCATION BECAME PIONEERS OF STEAM LEARNING 40 YEARS AGO, BEFORE THIS APPROACH TO LEARNING HAD A NAME

Why are you passionate about STEM/STEAM?

It's exciting to see a child figure something out, even if they fail at first. Allowing a child the opportunity to explore and discover through meaningful hands-on experiences not only teaches the child about that one thing, but also teaches them how to learn. I am so excited that I get to help bring these experiences to students around the world, where they get to experience subjects like math and science integrated together rather than in isolation, and learn skills that will be useful across any discipline.

Which is your favourite LEGO theme and why?

As a previous middle school teacher, I am most excited about our newest STEAM learning solution for middle school: LEGO Education SPIKE Prime. There is so much opportunity to integrate learning from all areas of STEAM with SPIKE Prime so that students can really experience the application of the content they are exploring.

WHEN WAS LEGO EDUCATION LAUNCHED AND WHY?

We are celebrating our 40th birthday this year! In 1980, LEGO saw the natural need for an education division when it noticed teachers were using the popular LEGO bricks in classrooms to engage students through hands-on learning. Building on the LEGO Group's belief in the learning potential of the brick, LEGO Education was formed. For the past 40 years, LEGO Education has helped pioneer innovative STEAM education solutions that build confidence and the skills that will help students succeed in school and beyond, including collaboration, problem-solving and computational thinking.

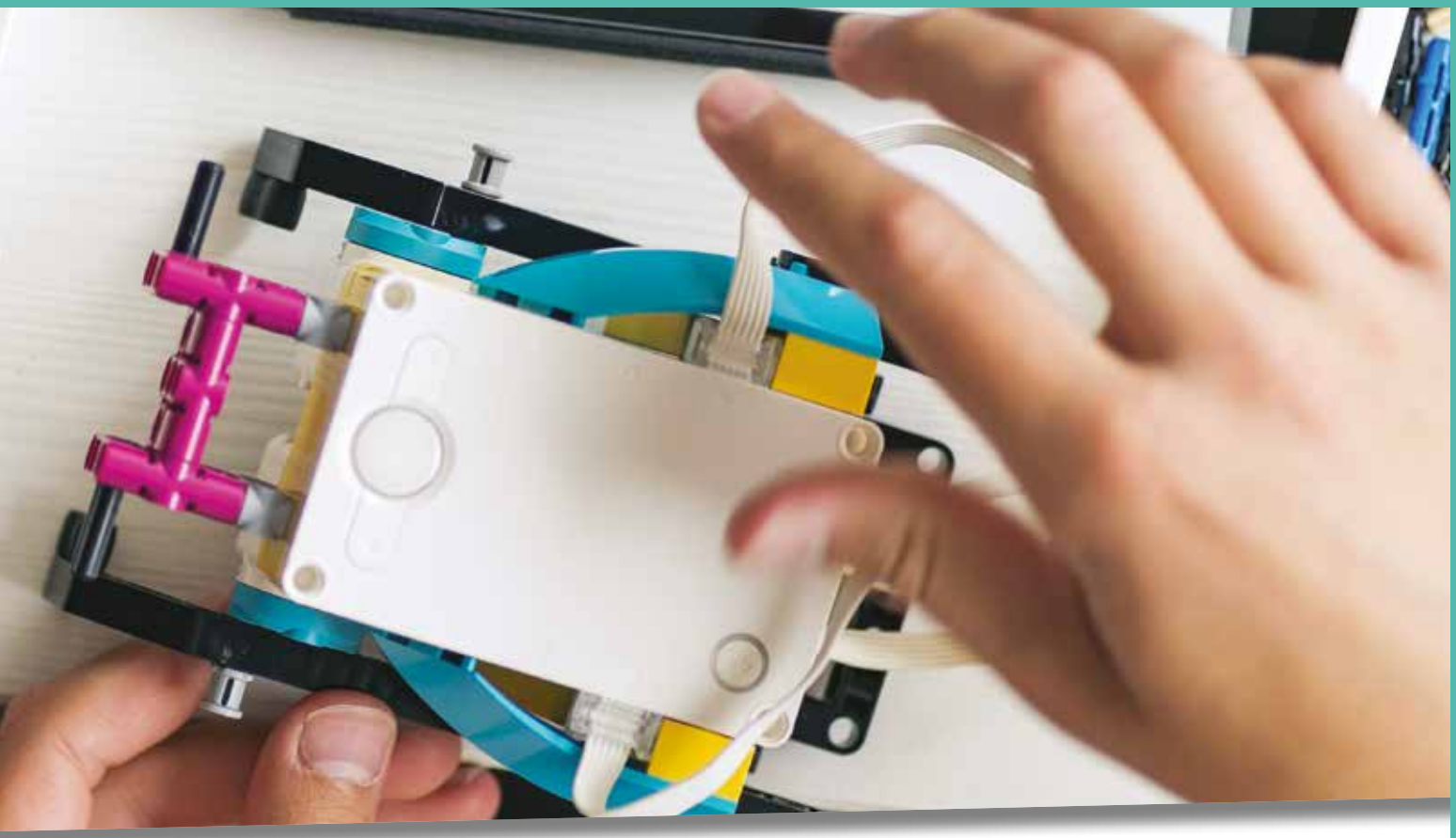
MANY OF THE RESEARCHERS WE WORK WITH SAY THEY PLAYED WITH LEGO AS A CHILD AND THIS, IN PART, INSPIRED THEM TO GO ON TO ENJOY A CAREER IN SCIENCE, TECHNOLOGY AND ENGINEERING. DOES THE TEAM AT LEGO RECOGNISE THE POTENTIAL TO INSPIRE CHILDREN ALL OVER THE WORLD IN THIS WAY?

Absolutely! It's right in our mission to inspire and develop the builders of tomorrow, enabling every student to succeed. Most students will go into jobs that don't even exist today, and many of those will be in STEAM or use STEAM skills, so all of our educational solutions are designed to inspire interest in STEAM subjects and help develop this skillset, as well as confidence in learning.

In fact, we were pioneers of STEAM learning before it had a name. In 1998, we created one of the first products that combined physical and digital learning when we announced LEGO MINDSTORMS. This was revolutionary at the time because most classrooms didn't have "makerspaces" or any hands-on way to teach kids about technology and engineering – in fact, it would be another three years before the term 'STEM' was coined.

We knew then that we were onto something, and we continue to create solutions that combine the physical LEGO bricks that kids know and love with the digital to teach them the 21st century skills they need to go into and thrive in STEAM careers.

RESEARCH SUGGESTS THAT BOYS' EXPOSURE TO CONSTRUCTION TOYS LIKE LEGO PUTS THEM AT AN



ADVANTAGE WHEN IT COMES TO EMBRACING STEM CAREERS. WHAT IS LEGO DOING TO ENCOURAGE GIRLS – AND PARENTS OF GIRLS – TO INTERACT AND ENJOY LEGO IN THE SAME WAY?

LEGO Education solutions are designed with every student in mind, no matter their gender, learning level or age. Hands-on learning is the best way to build student confidence, which means they will be more likely to try new things and keep trying even when they don't get it right on the first try.

Middle school is when we often see girls becoming less interested in STEAM subjects, which is why we created LEGO Education SPIKE Prime for middle schoolers with everything in mind – from the size of the bricks to the number of components to the colours designed – to inspire kids who aren't necessarily STEAM enthusiasts to try, test and build their confidence. Additionally, we consider the experiences and challenges that we present students through our lesson plans to ensure the themes are engaging and relevant to all students.

FIRST LEGO League is another great way to promote diversity and inclusion in STEM/STEAM. Not only are participants exposed to potential career paths in the season theme, but the global robotics programme also brings together students from different backgrounds, languages and interests, teaching respect and how to embrace our differences. We even see all-girls teams participate, which helps show that STEAM is for everyone.

ARE ALL OF LEGO'S EDUCATION INITIATIVES GLOBAL OR ARE THERE NATIONAL INITIATIVES, TOO?

Our goal is to reach as many students as possible, and so we work hard to make programmes available around the world. FIRST LEGO League has over 480,000 participants in over 110 countries. The LEGO Education Master Educator Program first launched in the United States in 2018, and has since expanded to the UK, Russia and Australia, with ongoing efforts to add additional countries in the future.

LEGO Education offers over 400 free lessons and resources for teachers, which are developed to be cross-curricular and align with local and national standards, including NGSS, CSTA and Common Core.

ARE THERE ANY CULTURAL ISSUES THAT THE LEGO EDUCATION TEAM HAS TO BE MINDFUL OF? FOR EXAMPLE, ARE THERE ANY INITIATIVES THAT WORK WELL IN ONE COUNTRY BUT NOT IN ANOTHER?

As a global organisation, we are mindful of global and regional trends and standards in education and put this knowledge and consideration into everything we do, from design to curriculum development. While STEM skills have become increasingly important for the future of work, different countries and cultures are embracing these skillsets at different rates.

For example, the Japanese government recently mandated coding and computer science curriculum for all public schools. Meanwhile, for the US, we map our curriculum to NGSS and CSTA standards. We work closely as a global team to ensure our products, curriculum and resources

JENNY'S TOP TIPS FOR STUDENTS

Become a confident learner. Learning is a journey that never stops, and students should take every opportunity they can to try something new. Whether it's learning to code, understanding the chemistry behind baking, or using math and physics to design a building.

Be a creative problem solver. Kids have an innate sense of curiosity, and it's that curiosity, willingness to jump in and innovation that will help them rebuild the world for the better.

are both accessible and relevant to what educators are teaching students around the world.

ARE THERE ANY NEW LEGO EDUCATION INITIATIVES IN THE PIPELINE? IF YES, WHAT ARE THEY?

We don't comment on future releases, but we are excited about our latest award-winning STEAM solution for middle school students, LEGO Education SPIKE Prime. SPIKE Prime brings together colourful LEGO building elements, easy-to-use software and the block-based coding language to engage students through playful hands-on learning, allowing them to think critically and solve complex problems. As a new school year starts for many students, we are excited to continue to offer and expand our resources for teachers that want to bring playful and hands-on STEAM learning into their curriculum.

CAN YOU GIVE A GENERAL SENSE OF THE BREADTH OF STEM SKILLS REQUIRED AT LEGO? FOR EXAMPLE, WHAT TYPES OF ROLES ARE NEEDED TO TURN A LEGO IDEA INTO A REALITY?

STEAM is a broad term that includes technical skills like coding and programming, as well as soft skills like collaboration, communication and creativity. Underlying all of these is the confidence and resilience to keep learning, try new things and embrace meaningful failure. When students become lifelong learners, they not only find success in the classroom, but also throughout their lives as family members, friends and employees. We can only predict what the jobs of the future might look like, but it's up to today's students to create and define them.

At LEGO Education, we have product designers, marketers, former teachers, engineers, sales leaders, and so much more. Speaking personally, I worked as a classroom teacher and then in higher education before joining LEGO Education. In my role here, I've brought together the best of both worlds to work with teachers and administrators to design and implement STEAM curriculum. I think working for LEGO is a dream job for so many, and I am continually impressed by the range of experiences and skillsets of my colleagues across the company.

WHAT DOES LEGO EDUCATION WANT TO ACHIEVE, ULTIMATELY? WHAT IS THE TEAM'S DREAM FOR CHILDREN ALL OVER THE WORLD?

Our goal is to reach as many children as possible to build the confidence they need to succeed in the future, the confidence to try and fail and learn and try again, no matter what's ahead. The best way to do this is through playful hands-on learning.

STEAM curriculum needs to be centred on building this kind of confidence and LEGO Education is leading the way. We are excited to continue building on and expanding our offerings to provide the tools and resources for all students to experience the joy of hands-on learning and ultimately become lifelong learners.

PLAYFUL LEARNING

JENNY DESCRIBES SOME OF THE INITIATIVES THAT LEGO EDUCATION HAS DEVELOPED FOR SCHOOLS, TEACHERS AND THEIR STUDENTS TO HELP MAKE LEARNING "FUN AND IMPACTFUL"

For more than 40 years we have been working with teachers and educational specialists to deliver playful learning experiences that bring subjects to life in the classroom and make learning fun and impactful. With our complete product continuum for PreK-12, we help teachers bring hands-on learning into their classrooms with free online lesson plans and curriculum material, assessment tools, and teacher training and support.

In response to the changing education landscape this year, we have created resources and guidance to ensure learning still happens – whether in-person, virtually or a hybrid of the two. You can find these resources online, including lessons, hygiene guidelines and classroom management tips.

We also recently launched a digital community to connect educators from around the world, giving them the place and space to connect, support, and learn from one another, as well as find and share inspiration, especially now when it's never been more important to stay connected and engaged.

The LEGO Education Master Educator Program brings together some of the brightest teachers who share our passion for using LEGO Education solutions to help students learn through play. Not only do we get the opportunity to learn from the Master Educators, but they connect with one another as a community of educators to share best practices. Our Master Educators have led by example in adapting to new ways of learning and continuing to teach STEAM from anywhere.

For over 20 years, we've partnered with FIRST to establish a guided, global robotics programme to help students and teachers build a better future together. FIRST® LEGO® League introduces STEM to children ages 4-16 through fun, exciting hands-on learning. FIRST® LEGO® League guides youth through STEM learning and exploration at an early age. Through three age divisions, students will understand the basics of STEM and apply their skills in an exciting competition while building habits of learning, confidence and teamwork skills along the way.

THE PLAYFUL PEDAGOGY

AS THE **LEGO FOUNDATION**'S LEAD ON THE TECH & PLAY AND PLAYFUL SCHOOLS INITIATIVES, **OLLIE BRAY** IS SPEARHEADING THE PLAYFUL PEDAGOGY, AN ETHOS THAT SEES PLAY AT THE CENTRE OF MEANINGFUL LEARNING EXPERIENCES FOR TEENAGERS AS WELL AS YOUNG CHILDREN

Ollie Bray is no wishful 'romantic' and, as a previous headteacher, knows full well that schools are controlled environments, but he is passionate in his belief that it is possible to adapt the formal school curriculum to include play. His role sees him leading the LEGO Foundation's Tech & Play and Playful Schools initiatives.

Tech and Play promotes learning through play with technology, incorporating Creative Coding (such as the block-based programming language, Scratch), System-based Robotics and Making and Tinkering.

Ollie highlights that the focus is on, "Discreet experiences linked to learning outcomes and how these experiences can be incorporated and scaled within formal education systems."

Playful Schools focuses on the importance of play in learning, teaching and assessment, as well as playful approaches to professional development and school design. As Ollie explains, "Schools have controlled parameters, but it is still possible to make schools more playful within these parameters." Emphasising the versatility of play, Ollie believes that the principles allow children to play with numbers, words and ideas, as well as the objects we might automatically associate with play.

THE 5 PRINCIPLES OF LEARNING THROUGH PLAY:

1. Socially interactive
2. Meaningful
3. Iterative (a repeated process)
4. Actively engaging
5. Joyful

EXAMPLES OF PLAYFUL PEDAGOGIES:

1. Project-based learning
2. Collaborative learning
3. Experiential learning

EXAMPLES OF PLAYFUL PARADOXES:

PLAY IS...	SCHOOL IS...
Timeless	Timetabled
Chaotic	Orderly
Risky	Safe
Child-led	Adult-led

"Sometimes it's okay to be less structured and to give children agency," says Ollie. 'Agency' is a word he uses a lot because children need to have ownership of their play – of their learning – to be both motivated and successful. "Play is risky by nature," he adds. In allowing students to take these risks, we allow them to define their own problems to solve, make their own decisions, fail or succeed on their own terms and, ultimately, learn and develop from meaningful learning experiences.

HELPING SCHOOLS TO EMBRACE THE PLAYFUL PEDAGOGY

One of Ollie's key aims is to help teachers recognise quality playful learning experiences. Partnered with Project Zero at the Harvard School of Education, the LEGO Foundation is creating lesson planning tools (linked to the principles of play) and lesson evaluation tools. Play is valuable but can only be incorporated into a formal school curriculum if teachers know how to make it valuable and to enable students to experience the 'genuine' joy that Ollie highlights as so motivating for them.

An important aspect of spreading the playful pedagogy is encouraging teaching staff to participate in project-based learning themselves, as well as leading their students through them. Ollie explains, "If you want to create a playful school, adults have got to be playful in what they are doing, as well." Ollie recognises teachers as researchers; a good teacher will be playful with their teaching, take measured 'risks' and take part in collaborative enquiry.

The benefits of project-based learning include seeing students collaborating in teams and leading their own learning. Though they will need to meet objectives and deadlines, they will not be working from a fixed idea at the start; their ideas and targets will develop as the project develops. "It's okay to go off on tangents because this is when the deeper learning happens," says Ollie. The playful pedagogy sees students, and the teachers who support them, learning and developing skills from this playful, flexible mindset – students can learn from 'playing' with other students, while teachers can be learning with their colleagues.

> ***"Being playful is not being childish; being playful is enjoying learning experiences that lead to tangible skills and deeper knowledge."***

WHO IS RESPONSIBLE FOR PROMOTING SUCH A DRIVE?

Ollie knows that there are many different education systems around the world and many different tiers within these systems. A focus on play and innovation needs to come from governments; leadership teams need to drive the approach in schools; middle leaders need to have the support and structure to be able to guide it; and teachers need to have the time and resources to be able to facilitate it.

While LEGO's emphasis on technology and innovation (especially with the Tech & Play initiative) is clear, Ollie also highlights the importance of the arts. Ollie cites tech products as evidence to this – such products are the result of STEM innovation, but it is the arts element that makes them beautiful and communicates them to the world. All subject areas across the curriculum have a responsibility to encourage students to be playful and innovative.

Though most of us will associate play with young children, Ollie is adamant that a playful approach to teaching and learning is appropriate for all ages. There are clear examples of 'playfulness' being key characteristics of many successful businesses. "Tech companies, for example, are often seen as playful in nature," says Ollie. In a world where we expect young children to play, and we see adults and tech developers being playful and taking risks, Ollie sees teens and young adults missing out. Being playful is not being childish, being playful is enjoying learning experiences that lead to tangible skills and deeper knowledge.

So, as the LEGO Foundation Initiative Lead and former headteacher, what is Ollie's mission? He says he is "driven by trying to help people understand what is possible." Teachers across the globe share this desire and, in his role, Ollie is aiming to help them to achieve it.

"IF LEGO CAN TAKE ME DOWN A PATH OF SUCCESS, IMAGINE WHAT STEAM COULD DO FOR YOU!"

DUE TO A GENETIC CONDITION, **DAVID AGUILAR AMPHOUX** WAS BORN WITHOUT A FOREARM, BUT HIS IMPULSE TO BUILD A PROSTHETIC ARM WAS BORN FROM HIS BOYHOOD PASSION FOR LEGO AND REJECTION IN LOVE. WITH A NEW DOCUMENTARY ABOUT TO BE RELEASED AND TONS OF HIGH-PROFILE SPEAKING EVENTS UNDER HIS BELT, DAVID TELLS US HOW HIS DETERMINATION AND LOVING FAMILY HAVE SET HIM ON A PATH TO HELPING OTHERS USING TECHNOLOGY AND BIOENGINEERING

DAVID AGUILAR AMPHOUX

Third year student
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To highlight his story about disability, determination and triumph, David is creating a brand called Hand Solo, which will be used to produce T-shirts, mugs, sweatshirts, hats and more. He is hoping that money from the proceeds will go to the Andorran Federation of Associations for Persons with Disabilities. Join David's disability awareness campaign and reach out to him and others via social media.

@handsolo99

Hand Solo

David AGUILAR AMPHOUX
aka Hand Solo

@DavidhandSolo

www.mrhandsolo.com

YOU WERE ONLY 9 YEARS OLD WHEN YOU CAME UP WITH THE IDEA OF BUILDING A PROSTHETIC ARM OUT OF LEGO. HOW DID YOU COME UP WITH THIS IDEA AT SUCH YOUNG AGE?

When I was younger, I was always more interested in disassembling the original LEGO toys and designing my own creations. So, at 9 years old, I had reached a point where I thought that the most exciting project ever would be to make a functional arm, by combining normal LEGO bricks with LEGO Bionicle parts. In the beginning, I operated an internal wire with my stump, which enabled me to open and close the legs of Bionicle robots, like a pair of tweezers.

YOU THEN BUILT YOUR FIRST OPERATIONAL ROBOTIC ARM WHEN YOU WERE 18. WHAT CHALLENGES DID YOU HAVE TO OVERCOME TO BUILD THIS ARM?

I have to admit that the reason I built the MK-1 [David's first prosthesis] was because I went through a major disappointment in my life. I was rejected by a girl for being disabled and that marked me a lot. I locked myself in my room for a week. One day, when I came home from school and locked myself in my room, I stared at a LEGO helicopter I had on my shelf. It was then I decided to disassemble it and create the project of my life.

The main challenge in building the arm was adapting it to my ergonomics. I had to use the little movement I have in my stump to give movement to the prosthesis and adapt it to the shape of my arm. Now, I can pick up objects, do push-ups and other endless tasks that I wouldn't be able to do without it.

IS IT TRUE THAT IRON MAN IS ONE OF YOUR FAVOURITE SUPERHEROES? ARE YOU HOPING TO BUILD AN IRON MAN-TYPE SUIT ONE DAY?

I love fantasy films and I have always liked Avengers. As a child, my favourite film was The Iron Giant; when I was older, it was Iron Man, without a doubt. I have to say that one of the greatest compliments I have received came from Marvel Studios co-founder Charlie Wen. He is also in charge of the design of the superheroes' costumes. When I was speaking at NASA's Cross Industry Innovation Summit about my prostheses and latest 3D-designed arm, he got up during my presentation and told me that I was the real Tony Stark – in front of the most important people and companies on the planet! You never know where destiny is going to take you.

YOU ARE STUDYING A BACHELOR'S DEGREE AT UIC BARCELONA.

WHY DID YOU CHOOSE TO STUDY BIOENGINEERING?

I study bioengineering because it's the most suitable degree for developing prostheses. It's possible I may do a Master's in robotics, but bioengineering is more relevant.

WHAT WILL YOU DO WITH YOUR DEGREE?

Above all, help people. Technology is available to everyone and 3D printers have evolved a lot. Many people use them to make standard prostheses using instructions from the internet. The problem is that not everyone has the same disability. A career in bioengineering will allow me to develop better prostheses. I also have an advantage: I can apply all the technology to myself to better understand whether or not it suits our needs.

WHAT WOULD BE YOUR DREAM CAREER AND WHY?

The truth is that another of my passions is music. I composed and produced the tune in my new documentary entitled Mr Hand Solo (don't miss it!). My father, who is also fond of music, composed a song for me that appears in the credits. He has instilled a love for music in me and, to me, it's a very exciting world technologically speaking. I would have liked to study music production, and I'm not ruling out doing something about it.

DO YOU THINK STEM SUBJECTS ARE A GOOD OPTION FOR YOUNG PEOPLE?

Without a doubt, STEM subjects give rise to important scientific advances. The democratisation of technology and lower costs mean that there is greater capacity to spearhead tomorrow's technologies. If a construction toy like LEGO can take me down a path of success, imagine what science, engineering or other STEAMM subjects could do for you.

WHAT ADVICE DO YOU HAVE FOR YOUNG PEOPLE WITH A DISABILITY OR HAVE OTHER PERSONAL CHALLENGES?

May you never lower your arms and stop fighting for your dreams. It's true that my father has helped me a lot, to grow and to be known throughout the world. He made prostheses to help me to ride a bicycle and, recently, he made one that allows me to ride an electric scooter to university, because public transport is almost impossible and very expensive. My mother and my sister are also fundamental to my personal development and have greatly influenced my story.

Growing up in this environment has influenced my life in a significant way. I am lucky and I admit it – it's easy for your fighting spirit to emerge when you have a loving home environment like mine. When you have no support or anyone to encourage you to move forward, it's more difficult. I can only advise that you fight for your dreams no matter what. There is always someone to turn to, to achieve your goals.

FINALLY, WHAT IS YOUR PROUDEST ACHIEVEMENT SO FAR?

I'm proud to have made five functional prostheses with my favourite toy, and experienced what it feels like to pick up objects from a distance, do push-ups, etc.

But the thing that makes me most proud is how my achievements are positively influencing others. I give presentations at international, educational, technological and motivational fairs, which means my story is reaching far and wide.

Not only that, but I'm helping to fight against bullying, which happened to me when I was a child. I think my story is helping a lot of people see disability differently. I believe in a more humane and inclusive world where people with different abilities are accepted and become more visible. My story, and the subsequent media attention, is allowing me to show the world that technology can help us overcome challenges. I really hope that this, combined with my studies in bioengineering, will help me become a great role model.

WATCH THIS:

The trailer to David's documentary: Mr Hand Solo:
https://vimeo.com/429319535/a675cb18a5

THE BIG SHAKE: DESIGNING TALL TIMBER BUILDINGS THAT ARE RESILIENT TO EARTHQUAKES

SIX UNIVERSITIES ARE INVOLVED IN A COLLABORATIVE RESEARCH PROJECT TO INTRODUCE A SPECIAL TYPE OF RESILIENT TIMBER BUILDING ACROSS THE UNITED STATES. THE **NHERI TALLWOOD PROJECT** AIMS TO PROVE THAT TALL TIMBER BUILDINGS CAN BE RESILIENT TO EARTHQUAKES, WHILE HAVING A WHOLE HOST OF OTHER ADVANTAGES

TALK LIKE A STRUCTURAL ENGINEER

Cross-laminated timber (CLT) – a type of wood panel created by gluing together layers of wood perpendicular to one another (similar to how plywood is manufactured).

Lateral loading – a horizontal force acting on a structure, such as wind, an earthquake or waves.

Mass timber – a category of framing techniques characterised by the use of solid wood panels and large-dimension wood columns and beams. CLT is a type of mass timber component.

Resilience – the ability of a structure to recover its functionality after experiencing the effects of an external disruptive force.

Rocking wall system – a type of structural design that allows walls in the building to move ('rock') when exposed to an external force and return to their original shape once the force has passed.

Seismic – an adjective used to describe effects related to earthquakes.

Shake table – a large platform that can reproduce earthquake ground shaking, used to test the seismic performance of buildings and other structures. The world's largest outdoor shake table used in this project is part of the NSF NHERI (Natural Hazards Engineering Research Infrastructure) programme, which provides this equipment to researchers when they need to test something really big.

Large-scale timber construction is on the up. New building techniques mean that many of the limitations of using wood are no longer insurmountable, and there is increased interest in timber as a sustainable building material. The production of steel and concrete accounts for 8% of all global CO2 emissions – a staggering amount – so finding alternatives for construction is essential. If harvested correctly, trees are a renewable resource and when they are incorporated into buildings, they also have an important role in keeping carbon out of the atmosphere.

Wood brings with it its own challenges. The danger of fire, for instance, requires careful attention, although the risks are much less than might be assumed and teams all over the world are helping to minimise these risks even further. Additionally, rigorous tests are used to investigate wood's structural capabilities, which are constantly improving as new engineering techniques are developed. Then, the buildings' responses to natural disasters, in particular earthquakes, must be considered. This is what the NHERI TallWood team focuses on.

The team consists of a mix of academics and practitioners, all keen on advocating novel construction methods. In particular, they want to demonstrate that their building techniques are resilient to earthquakes. Computer simulations and small-scale models are one thing, but the project aims to take it to the next level: to simulate an actual earthquake on a full-scale building. This involves a gigantic piece of equipment called a 'shake table', which does exactly what you might imagine.

DR SHILING PEI

Shiling Pei P.E.
Associate Professor
Department of Civil and Environmental Engineering
Colorado School of Mines

Role: Project lead, overseeing the collaborative efforts between the six universities involved, and preparing for the 10-storey shake table test.

Project: The NHERI TallWood Project aims to develop a resilience-based seismic design methodology for tall wood buildings of the future. This research project is supported by the National Science Foundation through a number of collaborative awards including: Civil, Mechanical and Manufacturing Innovation (CMMI) 1636164, 1634204, 1635363, 1635227, 1635156, 1634628.

Find out more about the NHERI TallWood project here:

http://nheritallwood.mines.edu/

Dr Shiling Pei (known as Ling) is the principal investigator of the project. He believes that large wood-based buildings have a strong future in the USA. "Almost 90% of residential buildings in the USA are constructed from wood because of its affordability and accessibility," he says. "Other countries use wood in their housing to different degrees – around 55% in Japan and next to nothing in China." It is difficult to build larger buildings out of traditional planks of wood, but through some canny construction methods that have been developed over the last couple of decades, wood buildings over 10 stories high can become commonplace.

MASS TIMBER

Mass timber is an engineered timber product that consists of multiple layers of timber, joined (laminated) together to form a solid structural component. The NHERI project focuses on the use of cross-laminated timber (CLT). CLT is made from lumber harvested from small diameter trees that are glued in perpendicular layers (crossways) under high pressure. These solid panels can then be cut to the desired shape.

"Mass timber expanded the wood building market by allowing the construction of large-scale commercial buildings using wood," says Ling. "It's a highly efficient pre-fabrication process that requires little manpower or time on the building site, which suits the shortage of manual labour common to many developed countries." It also has an aesthetic advantage too. "People love exposed wood, so much so that they will commonly cover concrete or steel building interiors with wood panels. So, why not just use real wood when we can?"

The cross-laminate process means that a lot of the construction work can be done off-site, and the prefabricated product then transported to the building site. This has plenty of advantages: it saves the cost of transporting a lot of construction machinery and workers to the site, and also means that the building process itself is relatively quick, which is good news for neighbours and local infrastructure. It has advantages over 'traditional' wood in that it can be built to any size and can be specifically engineered to be strong and resilient.

PROTECTING AGAINST THE FORCES OF NATURE

Natural disasters are often catastrophic for developed regions. Earthquakes and hurricanes, for instance, have been known to level entire districts. It is only in the last a few decades that urban buildings have been designed with earthquakes in mind – in the world of engineering, this is expressed through accounting for the phenomenon of lateral loading.

"Lateral loading is when a strong force comes from a horizontal direction, such as a strong wind or an earthquake," says Ling. This is opposed to the vertical force of gravity, which is constant. "Lateral forces are transient, dynamic and violent. Lateral resistance is how buildings counter them, and incorporating a lateral force-resisting system is a key focus for building design."

Lateral force-resisting systems need to have the strength to overcome lateral loading, and not deform so much that the building's structure is damaged. "A lot of existing lateral systems such as concrete walls or steel frames are very strong, but if they do get deformed, they are very difficult and expensive to repair." The team members think they have a solution: a resilient wood rocking wall system, where the building is allowed to deform to some degree and then spring back into shape. This is something that nature has been doing for millennia; you can see it in the bending of tree branches on a windy day.

THE WALL THAT ROCKED

Ling's team has designed a rocking wall system that should be able to resist earthquakes and other natural events. "It basically consists of a solid wood wall panel anchored to the ground using steel cables under tension. When exposed to lateral forces, the cables will allow the walls to rock up – which increases the building resilience – and can then pull the building back to plumb once the forces are gone."

In terms of physics, it is as if the building is held to the ground with big rubber bands. When a force pushes from the side, the rubber bands can stretch and allow it to move in that direction, before snapping back into their original shape once the force has passed. The concept is elegantly simple, but the design needs careful thought, which is what this NHERI TallWood project is all about.

THE SHAKE TEST

The NHERI TallWood team has access to the world's largest outdoor shake table, which is where they carry out their earthquake tests. "The shake table is basically a huge steel block foundation driven by hydraulic pistons that are controlled using computers," says Ling. It can even replicate past earthquakes using seismic recordings. For instance, the team already carried out a test on a two-storey mass timber building by simulating shaking from the Northridge Earthquake, a magnitude 6.7 earthquake that struck Los Angeles in 1994.

The next shake test on the table involves a much bigger construction: a ten-storey building. "This test will validate the resilience of our design methodology, and will also be an important opportunity to educate the public," says Ling. "It will demonstrate the potential benefits of constructing tall buildings out of wood and, with any luck, will also inspire the next generation of engineers and scientists."

THE POWER OF COLLABORATION

"The people are definitely the highlight of this project," says Ling. "Our team is a coalition of researchers, engineers, architects, contractors, representatives of the wood industry and project stakeholders." Upon completion of many scientific research projects, there is a time-consuming process to make their results applicable to the real world. By directly involving designers and manufacturers, the NHERI TallWood project skips this step and makes the process as seamless as possible.

DR JOHN VAN DE LINDT

John W. van de Lindt
Harold H. Short Endowed Chair Professor
Department of Civil and Environmental Engineering
Colorado State University

Role: Leading the development of the project's design methodology and helping to plan the 10-storey shake test for 2021.

RESILIENCE AND PERFORMANCE

Resilience is a vitally important part of structural engineering. It describes the ability of a structure to be able to 'bounce back' after it is impacted by a natural hazard such as an earthquake. Importantly, it is different from performance, which simply describes how well a structure can resist a force and keep damage to a minimum while protecting people inside. Resilience is often a better solution since performance only focuses on the building. Design codes based on performance minimally strive to preserve life safety, meaning people survive but the building may be unrepairable post-earthquake. The concept of resilience allows a building that becomes damaged to be more easily repaired and functional again, and support the recovery of the whole community around it.

BUILDING IN RESILIENCE

"There are two main ways that we can build resilience into a structure," says John. "The first involves basic design, limiting the movement of the building to avoid damage to its components, or directing damage to sacrificial 'fuse' components that are easily replaceable. The second involves a complex computer model that simulates repair following damage." It is often impossible to avoid all damage in the event of an earthquake, but minimising it and even channelling it to less essential or easily repairable components can help make the repair process as easy as possible.

"We aim to go a step further than resilience of individual buildings," says John. "We want to build in community resilience, which means that society as a whole can remain functional after the earthquake, to support social institutions, the economy and overall societal wellbeing. Resilient buildings are an important component of community resilience – they are built with the community in mind. Especially following a natural disaster, buildings like these could become focal points to help an area's recovery.

A mass timber building under construction in Denver, Colorado, USA

DR JEFFREY BERMAN AND DR DANIEL DOLAN

Jeffrey Berman
Professor
Department of Civil & Environmental Engineering
University of Washington

J. Daniel Dolan, P.E.
Professor
Department of Civil and Environmental Engineering
Washington State University

Role: Building computer models to simulate the effects of an earthquake on the buildings the team is designing.

VIRTUAL EARTHQUAKES

Before getting underway with the shake table, it is important to have a good idea of what is going to happen. Building a ten-storey building and then giving it a good shake is no easy task, after all, so it is advantageous to be able to anticipate as many potential issues as possible, especially if there are ways the building design could be improved beforehand.

"We and our graduate students are responsible for predicting the seismic response of the ten-storey test using computer models," says Jeff. "These will help us understand how the design might be changed to improve the building's resilience." The team has particular goals in mind – for instance, limiting the damage from earthquakes of a particular intensity. Ideally, they want buildings to suffer no damage from smaller (and more frequent) earthquakes, and only repairable damage from larger (infrequent) earthquakes.

"Our simulations are founded in the science of mechanics," says Jeff. "Using advanced programming and applied math, the computer models replicate the physics of a building in an earthquake. This is actually quite complicated and involves a lot of learning to get it right."

A SECOND ROCKING JOINT

The team is investigating whether a second rocking joint could be beneficial. So far, the building rocks at ground level, before being pulled back into position. It is possible that putting a second joint halfway up (at the fifth storey) could further increase resilience. However, this brings its own challenges – for instance, ensuring the building and all its individual components have the capacity to be able to bend at this joint and fall back into place afterwards.

"So far, we have found that these CLT wall systems have excellent seismic performance," says Jeff. "They limit the damage to the structural components of buildings even in large and infrequent earthquakes."

DR KERI RYAN

Keri L. Ryan
Professor
Department of Civil and Environmental Engineering
University of Nevada, Reno

Role: Incorporating resilience into non-structural components of the building.

BEYOND THE ROCKING WALLS

Keri's role focuses on the building's non-structural components and their resilience to earthquakes. These are integral parts of a building that do not directly contribute to holding it up: for instance, interior walls, stairs and elevators, as well as plumbing, and electric and ventilation systems. "Research on resilient non-structural components is still in its infancy compared to structural systems," says Keri. "A shake table test that we conducted back in 2011 was what first alerted me to the amount of damage they sustain."

"Most seismic engineering research to date has focused solely on the lateral resistance of structural components," she continues. "However, non-structural components are often highly damaged during earthquakes. After the 1994 Northridge Earthquake, about half of the damage cost to buildings was due to non-structural components. This highlighted the need to address vulnerabilities in non-structural systems."

Even if a building remains structurally sound after an earthquake, non-structural damage can ultimately harm its structural integrity. For instance, damage to exterior cladding (the building envelope) can mean that the underlying structure is exposed to weather. Many non-structural components are also crucial to a building's safety. Damage to stairs, for instance, can trap occupants within a building after a natural disaster, as happened in the 2011 Christchurch Earthquake in New Zealand.

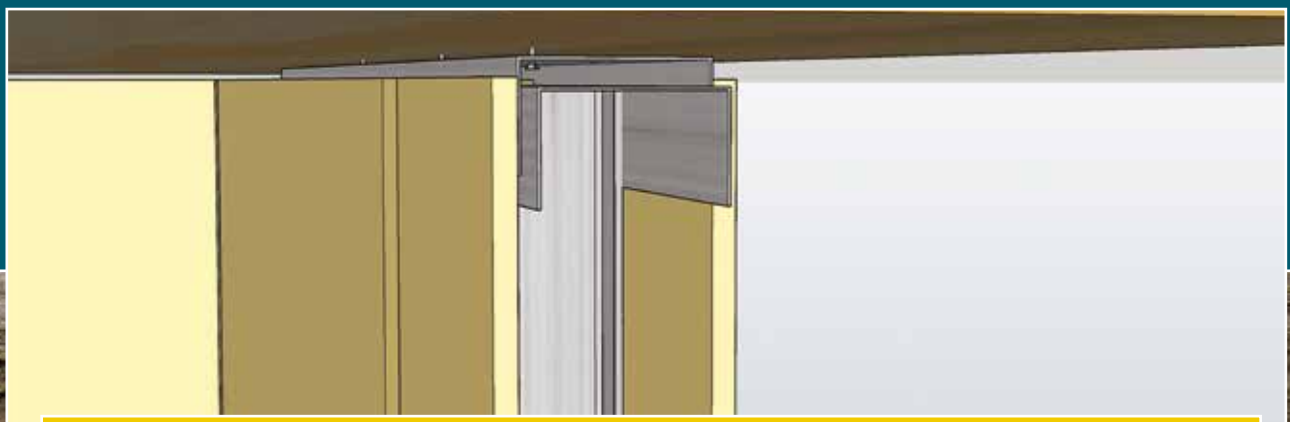
ALONG THE WALLS AND UP THE STAIRS

The rocking wall system only works if everything moves with it. If the building's structure is designed to flex during an earthquake, the parts within its interior need to move with it or risk getting crushed or broken. This is known as deformation compatibility. "We are focusing on interior walls, the building envelope, and stairs as the most integral non-structural components," says Keri. "We are working closely with designers and other specialists to identify how to make improvements wherever we can."

For interior walls, they are investigating an innovative solution known as a 'slip track'. "This is when the top of the wall is not directly connected to the above floor slab, and thus can move independently or slip relative to the floor above." This works well until these walls meet at corners, at which point there is the risk of collision and damage. Now the team is working on the finer details of how to minimise damage at the corners.

Stairs are also a big area of interest. "Stairs are typically rigidly connected between floors and are often damaged during earthquakes, and are then deemed unsafe for future use," says Keri. "US building regulations have changed to address this, but there's still a lot of research that needs to be done to get the best design." Similar to interior walls, the prime solution is to detach the stairs from the floor at one end, so if the floors move independently the stairs are not stretched or compressed between the two. The team has partnered with a construction innovation company and will compare several solutions to solve this challenge.

Left: Drift ready connection that accommodates relative movement between the stair flight and the landing. Right: Drift ready connection hardware. Courtesy of Construction Specialties, Ltd.



Slip track detail; inner track and wall slip with respect to the outer track that is secured to the floor above. Courtesy of PhD student H. Hasani

DR JAMES RICLES AND DR RICHARD SAUSE

James M. Ricles
Bruce G. Johnston Professor of Structural Engineering
Civil and Environmental Engineering
Lehigh University

Richard Sause
Joseph T. Stuart Professor of Structural Engineering
Civil and Environmental Engineering
Lehigh University

Role: Investigating the effects of lateral force using subassemblies.

FROM THE SIDE AND THE FRONT

The Lehigh team investigates the lateral resistance of timber buildings with CLT walls. In particular, they examine bidirectional loading, which is when lateral force comes from several directions at once, as is common with earthquakes. For walls, this means examining what happens when forces parallel to the wall (for which it is designed) combine with forces perpendicular to the wall. The team is investigating this by building a constituent part of the building's walls and adjacent floors (a subassembly) and then using hydraulic actuators to subject the building to bidirectional forces.

"We developed specific software for these tests," says James. "The software uses real-time data, which gives it a highly realistic output." It also considers the interaction of walls with other components of the buildings, such as stairs and floors. This is important as any part of the building can influence its overall resilience, so making sure to account for everything is crucial. It is the first time that these walls have been tested in this way in the USA.

RESULTS FOR THE REAL WORLD

"Testing a large-scale building requires careful consideration of what we aim to find out," says James. "This is in addition to managing costs and schedule, as well as maintaining a safe environment for the research team." They must always make sure that their results reflect something of real-world value, something that usefully expands the knowledge available on this topic.

"We have found that the walls get damaged more easily when exposed to bidirectional loading rather than unidirectional loading," says James. "This has important implications for the building's seismic resilience, which will help us finalise the design details for the 10-storey building."

Isometric bottom-side view of test sub-assembly

Test sub-assembly under birectional loading

Isometric top view of test sub-assembly

CIVIL ENGINEERING AND STRUCTURAL ENGINEERING: WHAT'S THE DIFFERENCE?

Civil and structural engineering are two branches of engineering. In some ways they are closely related, but careers-wise they can follow quite different paths. In brief:

- Civil engineering is broader in scope and includes structural engineering as a specialty. General civil engineering tends to concern large-scale public systems, such as land development, transportation systems, water and energy distribution systems, and dams.

- Structural engineering concerns structures such as bridges and skyscrapers. It is focused on designing structures using steel, concrete, wood and masonry materials.

In terms of education, it is unusual to see a direct focus on structural engineering at the beginning of undergraduate study. Within civil engineering, students will often have the option to specialise in structural engineering at the end of the programme.

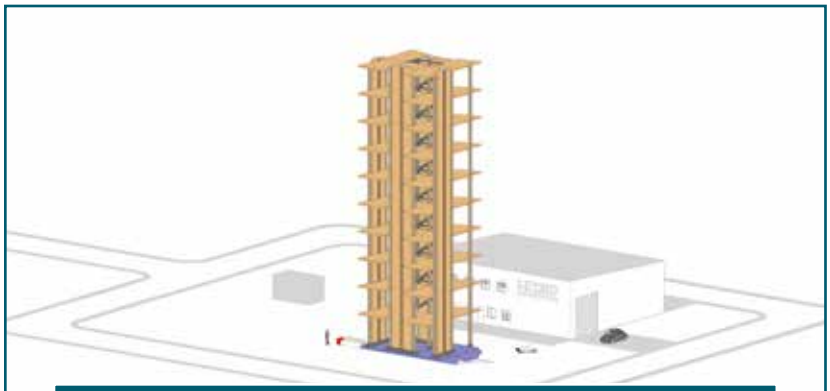
GETTING INTO CIVIL ENGINEERING

- According to Top Universities, the best universities for civil engineering in the world are MIT, Delft University of Technology (Netherlands), Cambridge, University of California – Berkeley, and Imperial College London.

- According to the Institute of Civil Engineers, useful subjects to take to prepare for a civil engineering degree are maths, physics, geography and geology, computer science and languages.

- Civil engineering careers do not always require a degree. Apprenticeships are relatively common for this discipline both in the US and the UK. In the UK, the top employers for engineering apprenticeships are BAE Systems, National Grid and BAM Nuttall.

- Civil engineering is often a well-paid career. The average civil engineer in the US makes around $87,000 a year, according to US News.



Full-scale 10-storey wood building to be tested at NHERI@UCSanDiego. See: http://nheri.ucsd.edu

The research team pose on a two-storey mass timber structure, tested in 2017.

HOW CAN URBAN TREES REDUCE FLOODING AND POLLUTION?

DR TRISHA MOORE IS A BIOLOGICAL AND AGRICULTURAL ENGINEER BASED AT **KANSAS STATE UNIVERSITY** IN THE US. HER RESEARCH IS WIDE AND VARIED, COVERING BOTH URBAN AND RURAL ENVIRONMENTS. HER MOST RECENT RESEARCH IS FOCUSED ON UNDERSTANDING HOW URBAN TREE SYSTEMS CAN MITIGATE THE NEGATIVE IMPACTS OF STORMWATER RUNOFF

A 2015 study involving 421,529 measurements from 50 countries on six continents found that there are more than three trillion trees on our planet – roughly 400 trees for every human. That's a lot of trees and thank goodness – they do the world a tremendous amount of good: they absorb carbon dioxide which helps slow the rate of global warming; they reduce wind speeds; they can cool the air; and they are beautiful to look at and walk amongst.

And now a team of researchers is investigating whether trees might also be able to mitigate the negative impacts of stormwater runoff in urban areas. Dr Trisha Moore, based within the Department of Biological and Agricultural Engineering at Kansas State University in the US, is the Principal Investigator of a Water Research Foundation project that is trying to document the contribution of urban tree systems to stormwater nutrient and volume control.

WHAT ARE THE MAIN PROBLEMS CAUSED BY STORMWATER RUNOFF IN URBAN AREAS?

Stormwater, as the name suggests, is that which is produced through heavy rainfall during a storm. One of the main problems is flooding, which occurs when the grates at the side of the streets and the pipes underneath the roads cannot handle the amount of rainfall. This flooding tends to bend to the will of gravity, so people living downhill often bear the brunt of the damage that stormwater causes.

Then there is the problem with the quality of the stormwater runoff. "As stormwater runs across our rooftops, lawns, streets and other surfaces in the urban landscape, it picks up all sorts of pollutants and carries them with it," explains Trisha. "So, for example, you can have sediments washed from streets muddying up streams and smothering aquatic habitats, and a cocktail of heavy metals, salts, pesticides and other chemicals that cause harm to aquatic food webs."

HOW CAN TREES AND NATURAL VEGETATION HELP COUNTER THESE PROBLEMS?

It is known that trees and natural vegetation generally provide a buffer to some of the negative impacts associated with stormwater runoff. However, Trisha's project wants to quantify the magnitude of this buffering effect. To achieve this, the team conducted a meta-analysis, where the researchers look through all the studies that have been conducted in a particular area to examine the insights they provide as a whole. "A meta-analysis begins with a thorough literature review – through this, we identified all the studies to date in which the ability for urban trees to capture rainfall has been measured," says Trisha. "Then we extracted the raw data from each of these studies and ran various statistical analyses on this entire dataset." Ultimately, this method provides a better picture of what the studies are saying as opposed to the results from one or two studies.

WHAT METHODS DID THE TEAM USE IN THEIR INVESTIGATIONS?

Trisha and her team used a hydrological model known as i-Tree Hydro. Hydrological models estimate the volume of runoff and quantity of pollutants that would result for a given storm event in a given location. "There are many different models available, but we selected i-Tree Hydro because it explicitly represented the effects of urban tree canopy in urban areas," explains Trisha. "It is also a tool that is readily available to stormwater managers and municipal

foresters, who were the target audience for our project."

HOW IMPORTANT HAS COLLABORATION BEEN TO THE PROJECT?

Extremely important. Trisha is keen to emphasise the different skills that everyone brought to the project and enabled the investigations to be successful. "In this project, I partnered with a forester as well as people working in more of a policy role with local governmental organisations," says Trisha. "My role in this collaboration was to provide knowledge of urban hydrologic science and engineering to the project, the forester brought an extensive knowledge of trees, the policy collaborators brought practical knowledge and experience from working with cities, developers and decision makers on 'green' stormwater management initiatives."

HOW EFFECTIVE ARE URBAN TREE CANOPIES IN DEALING WITH STORMWATER-RELATED ISSUES?

Trisha's analysis showed that urban tree canopies can capture almost 50% of rainfall for storms up to 25mm when the trees have leaves, and up to 20-30% for storms with more than 50mm. However, as with many questions involving ecological systems, so much depends on the specific circumstances. "While deciduous trees capture a similar amount of rainfall as evergreen during leaf-on periods, if you live in a place that gets the majority of its precipitation during the winter months, then evergreen trees are going to provide a greater stormwater benefit," explains Trisha. "If you live in a place where summer thunderstorms cause localised urban flooding, then evergreen or deciduous trees may have an impact to slow and decrease runoff and associated flooding."

Although there are complexities, Trisha and her team are hopeful that the outcomes from their meta-analysis and the i-Tree Hydro modelling will provide stormwater managers with new tools and insights that justify including urban tree canopy expansion and preservation in their stormwater management plans.

DR TRISHA MOORE

Associate Professor, Department of Biological and Agricultural Engineering, Kansas State University, USA

FIELD OF RESEARCH

Biological and Agricultural Engineering

RESEARCH

Trisha's research focuses on the application of ecological principals to engineering design and management to improve the quality of our aquatic ecosystems.

Her most recent project uses meta-analysis and hydrological models to quantify the extent to which trees might be able to mitigate the negative impacts of stormwater runoff in urban areas. The findings could prevent flooding and pollution.

FUNDERS

State of Kansas, Kansas Water Resources Institute, Kansas Water Office, Water Research Foundation, U.S. Department of Agriculture

ABOUT BIOLOGICAL AND AGRICULTURAL ENGINEERING

One of the things that Trisha loves about the field of biological and agricultural engineering is that it encompasses diverse areas of research and technological applications. Through close collaboration, scientists with different skills and expertise are able to develop engineering solutions to a wide range of problems that have the potential to benefit people and nature.

Though Trisha has clearly spent much time studying the importance of the urban tree canopy, this is by no means the sum of her work. Trisha, and biological and agricultural engineers like her, work to understand the processes by which natural-based engineered systems contribute to the production of ecosystem services. One project could see her looking at water quality, while another could see her analysing stream erosion, while another will involve her studying climate regulation. Carrying out research in both urban and rural settings means Trisha is rarely without a fascinating project to get her engineering teeth into!

WHAT DOES TRISHA FIND MOST REWARDING ABOUT HER WORK?

Trisha's work is driven by a desire to make the interface between people and biological systems more sustainable – something that is especially important given climate change and global warming. "I design and study systems that are modelled after natural ecosystems and designed to protect aquatic systems from pollution, flooding or other disservices caused by human activities," explains Trisha. "Having a role in protecting our natural resources is very rewarding." She also believes that what is good for the resource is good for all of us – cleaner water in our streams and lakes is better for anyone who fishes, swims, watches wildlife, drinks or irrigates from aquatic resources.

HOW DOES TRISHA APPROACH PROJECTS WITH SIGNIFICANT COMPLEXITIES?

Ecological systems are complex. We humans are part of those systems, and any time we make a change to that system, it is likely to change in ways we do not expect. Another area in which Trisha works – streambank management and restoration – provides a prime example of this. In some cases, efforts to prevent streambank erosion actually have the potential to accelerate it. Clearly, streams are complex systems and there are a lot of factors to consider when attempting to develop engineering solutions. "Stream restoration and stabilisation is as much art as it is science – and that is part of what makes working in these systems fun! To try to better understand the science so that we can design and install these systems with better, more predictable outcomes," says Trisha. "A few of the factors to consider include the type of stream and if it is actively degrading (that is, eroding more than it builds up sand bars or other features) or if it is more of a dynamic equilibrium (that is, eroding but also depositing material at a similar rate so that the overall dimension of the stream is not changing)."

In Kansas, where Trisha works, the majority of streams are privately owned, so to make any project successful the team might have to work with 10 different landowners on either side of the stream. Therefore, any design that the team comes up with must be feasible from the point of view of several landowners.

WHAT ARE THE BIG ISSUES FACING TODAY'S BIOLOGICAL AND AGRICULTURAL ENGINEERS?

A huge challenge facing scientists around the world is ensuring the ever-increasing global population has access to food, clean water, and other ecosystem services, at the same time as ensuring that we sustain the planet's ability to provide these services. Biological and agricultural engineers are no different. As Trisha points out, "These issues directly impact all of us and transcend any one discipline or group of experts. This is another reason that biological and agricultural engineers (and, in my opinion, anyone working on these problems) should also strive to work collaboratively with people in other disciplines."

HOW TO BECOME AN AGRICULTURAL AND BIOLOGICAL ENGINEER

- The American Society of Agricultural and Biological Engineers is a vast resource for those interested in sharing ideas and advancing their careers: https://www.asabe.org
- The International Commission of Agricultural and Biosystems Engineering is a global organisation that brings together the agricultural engineering community: http://cigr.org/
- Agricultural engineers can expect an average salary of around $71,730, depending on experience and where in the US you are based. Engineering jobs pay typical salaries of around $91,000, while academia and research positions pay around $51,000.

Students in Trisha's research team measure eroding streambanks.

HOW DID DR TRISHA MOORE BECOME AN ENGINEER?

WHAT INTERESTS DID YOU HAVE AS A CHILD?

I really enjoyed the outdoors and was interested in anything I could find or do there – turtles and snakes, strange-looking insects, wading in streams, hiking trails and camping with my family. One of my fondest memories is trying to catch bullfrogs (and sometimes succeeding) in the ponds near my house on warm summer evenings. I also really enjoyed reading. My dad is a wildlife biologist and my mom was a librarian, so it is no surprise that I was drawn to these things.

WHY DID YOU TAKE THE CAREER PATH YOU DID?

Maths and science were among my favourite subject areas in school. I considered studying the biological sciences, and specifically herpetology – I was really fascinated by reptiles and amphibians growing up, but a couple of things swayed me toward engineering. First, during my senior year of high school, my physics teacher encouraged me to apply for a local scholarship that helped support students from my town majoring in engineering. Second, I have an aunt who is a civil engineer and encouraged me to consider engineering because (and I am paraphrasing here) the world needs engineers who understand both the physical aspects of design but also the environmental and ecological systems which they work within. She opened my eyes to environmental engineering and the role that engineers can play to protect and/or restore the environmental systems (e.g. streams and rivers) and resident fauna (e.g. turtles and frogs) in which I was so interested. I think I was the only applicant for the local scholarship, so I was on the hook to pursue engineering at my university after I accepted it!

HOW DO YOU MOTIVATE YOURSELF WHEN YOU FACE AN OBSTACLE?

I find that many of the obstacles I encounter are because of the way I am thinking about the problem. For me, the best way to give myself space to think about it differently is to take a break and go for a run. I find I am better able to examine the problem from a different perspective, iron out alternative strategies and think about the people who could help me tackle the issue.

WHAT NON WORK-RELATED ACTIVITY IS ON THE TOP OF YOUR 'BUCKET LIST'?

I have enjoyed running since I was a young girl and have even ran marathons. One of my bucket list activities is to complete an ultramarathon at some point in the future!

PATHWAY FROM SCHOOL TO BIOLOGICAL AND AGRICULTURAL ENGINEERING

"Math and science are really important to any engineering discipline. For biological and agricultural engineering, it helps to have a background in natural and earth sciences (e.g. biology, environmental science, geology) as well as physics and chemistry," says Trisha. "So, any courses you can take that expose you to these areas will be helpful. Gaining some background in sociology or other human-centric courses can also be valuable."

2 or 3 A levels, or equivalent.

Entry-level jobs in agricultural engineering require a bachelor's degree, preferably in agricultural or biological engineering. Agricultural engineers who offer their services directly to the public must be licenced as professional engineers.

https://www.environmentalscience.org/career/agricultural-engineer

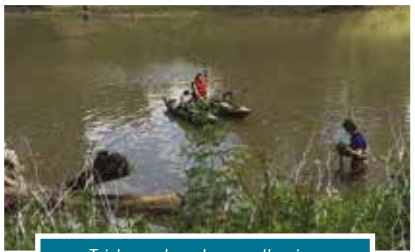
TRISHA'S TOP TIPS

1. Be persistent! Engineering coursework is notoriously challenging, but I think it is well worth the effort to set you on a path to contribute to solutions to many of the environmental challenges facing our planet.

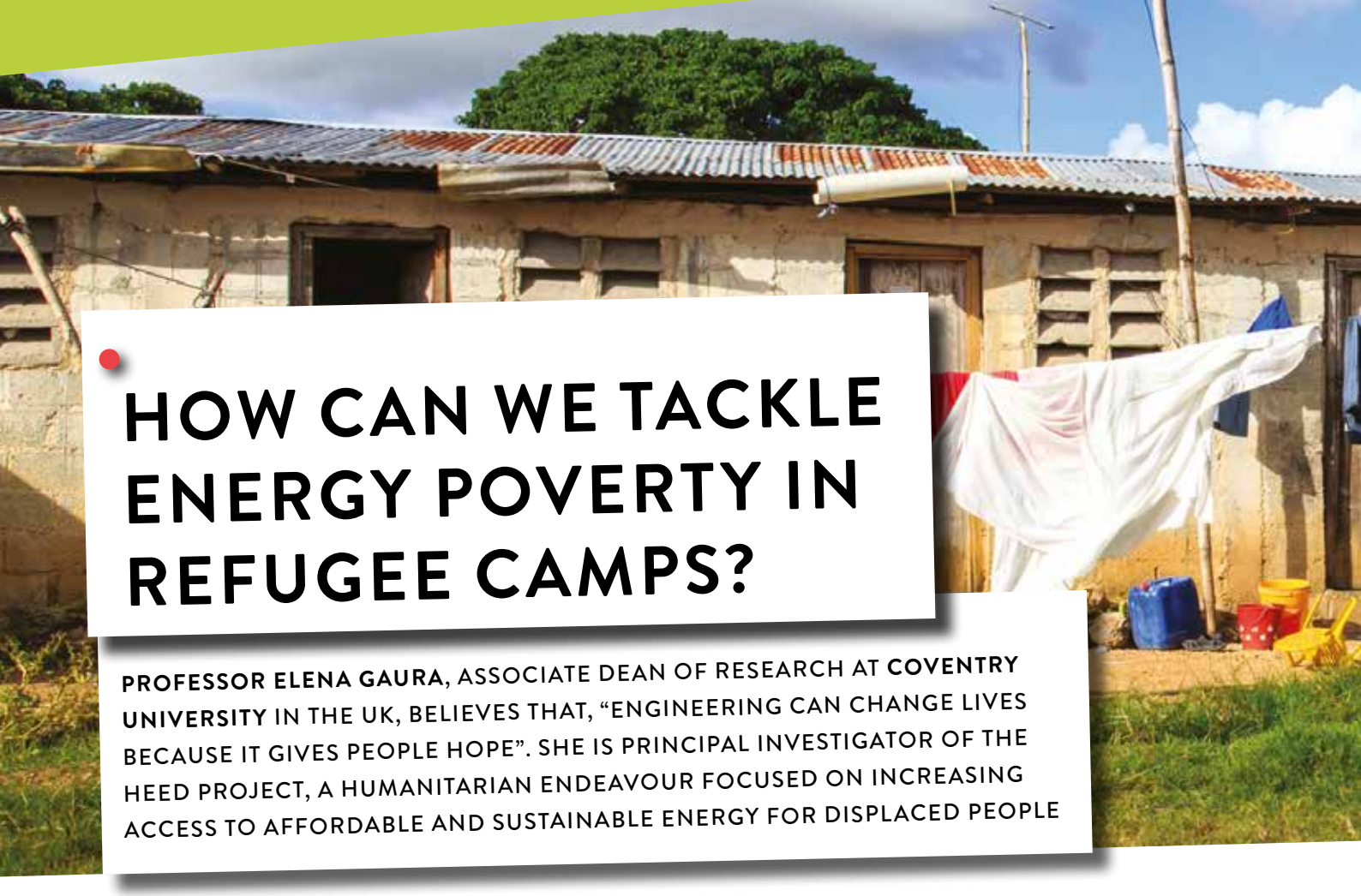
2. Be open to listening to and working with people from other academic disciplines and backgrounds. The global challenges we face transcend any single area of expertise, so I believe you can make an even bigger impact if you are able to work collaboratively with people from diverse backgrounds.

3. We tend to emphasise technical coursework for an engineering career, but strong communication skills – especially written – are extremely important for engineers. So, pay attention in your English courses and take technical writing classes if you get the opportunity.

Trisha sampling aquatic insects in a stormwater wetland.



Trisha and students collecting streambed elevation data by raft.



HOW CAN WE TACKLE ENERGY POVERTY IN REFUGEE CAMPS?

PROFESSOR ELENA GAURA, ASSOCIATE DEAN OF RESEARCH AT **COVENTRY UNIVERSITY** IN THE UK, BELIEVES THAT, "ENGINEERING CAN CHANGE LIVES BECAUSE IT GIVES PEOPLE HOPE". SHE IS PRINCIPAL INVESTIGATOR OF THE HEED PROJECT, A HUMANITARIAN ENDEAVOUR FOCUSED ON INCREASING ACCESS TO AFFORDABLE AND SUSTAINABLE ENERGY FOR DISPLACED PEOPLE

Having access to the electricity and other forms of energy needed for cooking, heating and lighting is something many of us take for granted. But, according to the International Energy Agency, there are almost a billion people around the world without access to electricity. This 'energy poverty' affects regions around the world, but particularly affects people in refugee camps and those who have been displaced as a result of war and natural disasters.

To address the challenge of finding solutions to the lack of energy for displaced populations, the Humanitarian, Engineering and Energy for Displacement (HEED) project has been established. Led by Coventry University in the UK, with partners Practical Action and Scene, HEED aims to rethink the way lighting, electrification, cooking, heating and cooling, and water and sanitation systems are designed to encourage safe, scalable and sustainable solutions. To achieve these aims, the project draws on social science and engineering expertise.

Professor Elena Gaura is the Principal Investigator of HEED. The project focuses on Congolese refugees living in three refugee camps in Rwanda (Nyabiheke, Gihembe and Kigeme) and people who were forced to leave their homes as a result of the 2015 earthquake in Nepal. Elena believes that simply providing energy to populations who don't currently have it is not enough to curb energy poverty; the end-users need to be part of the process of creating and designing the solutions. It is essential that the technologies that are developed and used are effective and have high utility, i.e. meet the needs of the population and serve the purpose they were created for.

HOW DID ELENA ENGAGE WITH END-USERS AT THE OUTSET?

The team behind HEED see energy systems as socio-technical, meaning they have positive impacts that go beyond merely providing energy. "For the success and sustainability of the social eco-systems within which energy solutions are situated, it is important that there is active community involvement," explains Elena. "We therefore listened to end-user voices in all settings, such as households, businesses and community organisations, before selecting and proceeding with the energy provision interventions."

To this end, refugees were employed to survey communities about their energy needs and aspirations. Workshops were also run by the team in Nepal and Rwanda that engaged the communities in the design and implementation of the energy interventions, such as where solar street lights would be situated in the camps, for example. This vital communication with end-users provided insights into how the lack of access to energy impacts on people's daily lives. By including women in devising energy solutions, the HEED project also addressed gender inequality. For example, with a daytime focus on household chores, women had less time to take part in leisure or educational activities. The engagement with end-users highlighted the need for street lighting so that women could feel safe walking around at night; they could make the most of their free time after their household chores.

WHAT TECHNOLOGY WAS USED AND WHAT DATA DID IT GENERATE?

The team behind HEED wanted to build an evidence base on energy usage in the displaced context to develop energy solutions that provided not only for existing needs but also for future demands. To achieve this, they deployed several wireless sensor technologies which enabled them to collect data in real time and in-situ. "The data arrived directly from the household settings, sensorised energy installations, cookstoves and lanterns to our computers in our lab. This made all of the interventions and energy devices used by the many hundreds of refugees households participating in the project part of the Internet of Things," says Elena. "The sensors gave us data on everything, including the use of mobile solar lanterns provided to refugees, sockets installed on the streetlights, or lights in the buildings."

HOW HAS HEED ENABLED END-USERS TO TAKE OWNERSHIP OF THEIR ENERGY/COMMUNITIES?

Elena explains, "Technologies that are well devised help build community resilience; energy systems can transform collectives of people

TECHNOLOGICAL CHALLENGES AND HOW TO OVERCOME THEM

Throughout the course of the HEED project, Elena and the team encountered many challenges. Below are some of the challenges they faced and how they continue to work to overcome them.

COOKSTOVES

The data collected from the cookstoves on the difference between fossil fuel and alternative energy cooking temperatures can provide a better understanding of existing energy usage patterns. This information could help with future designs of cookstoves to make them more affordable and efficient, in terms of fuel consumption.

MICRO-GRIDS

The team wants to understand the impact that energy usage and demand patterns have on system performance, but also on the community. "There is still a large amount of extra energy available from our systems, so we are trying several initiatives to further promote ownership and self-governance to increase energy utilisation," says Elena. "We hope that this will have a positive impact on the lives of the refugee communities and the longevity of the installed systems."

SOLAR ENERGY SYSTEMS

Some camp residents, particularly in Nepal, were distrustful of using the solar-powered sockets attached to the streetlights to charge their phones. "Some believed that charging with batteries powered by solar energy could damage their phone," explains Elena. "We feel that there is much more work to be done in terms of education about solar energy to encourage the increased usage of the HEED sockets." The team believe that, as humanitarian engineers, they have to find ways to communicate why renewable energies are a preferable option to fossil fuel-based energy systems.

PROFESSOR ELENA GAURA

Associate Dean of Research, Faculty of Engineering, Environment and Computing, Coventry University, UK

FIELD OF RESEARCH

Engineering and Computing

RESEARCH PROJECT

Elena's research is focused on increasing access to affordable and sustainable energy. The HEED project adopts a data-centred approach to knowledge that draws upon individual narratives to understand energy demands in the context of displacement with far-reaching societal and environmental impacts.

FUNDERS

Engineering and Physical Sciences Research Council (EPSRC)

(such as those in refugee camps) into 'energy communities' that own, govern and share the sun's gift of energy."

For example, in one of the Rwandan camps, the solar panel microgrid system developed by HEED means that the community now has an electricity supply that meets their specific needs. The playground and two nursery rooms now have electricity. The outside area can be used as a community space at night, for children to play in and for adults to charge their phones. Inside, older students can use the space to complete their homework in the evening. Elsewhere, street lighting has made women feel safer at night, empowering them to spend more time out in their communities. In addition, the solar street lighting was designed to store spare energy and provide it at multiple socket points at the base of the lights. These sockets offer free energy for everyone to charge phones, laptops, and battery-operated devices, which helps the community to claim ownership of the energy interventions as it is a communal asset.

Having access to phone charging, a space for homework, lights at night – things we often take for granted – enables displaced people to live more comfortable lives and in communities that are designed by them and for them.

HEED WANTS TO EMPOWER COMMUNITIES FOR THE LONG-TERM. HOW WILL THIS BE ACHIEVED?

The structures that have been put in place to help communities were analysed from the beginning, which enabled the team to identify and address knowledge gaps that can undermine community ownership. Everyone has to buy into the project for it to succeed in the long run; Elena believes that an element of community financial gain could help sustain the shared power supply interventions and encourage community driven innovation in other areas. "We have also considered that increasing the capacities of service providers, such as community projector screenings, shared water heating for cooking or washing, or water pumps for agricultural needs could improve community resilience and capability," explains Elena.

HAS HEED HELPED THOSE WHO ESTABLISHED THE PROJECT, AS WELL AS DISPLACED COMMUNITIES, TO RETHINK ENERGY POVERTY?

In a word, yes. Elena feels that the project offered participants the opportunity to look at the role of science through a different lens. "Throughout the project, I felt a sense of empowerment supported by the capacity of the project and the way the project is driving science to 'do good'," says Elena. "But I also felt enormously humbled, realising how much we don't know about the lived experience of displaced communities in engineering, how many answers we don't really have, and how much those answers are needed now. I think this project has been the most enriching experience of my career so far."

ABOUT PERVASIVE COMPUTING

Pervasive computing (also known as ubiquitous computing) refers to how computational capabilities are embedded into everyday objects, such as clothes, cars, homes, or environments and contexts, such as parks, open areas, roads and transport infrastructure. The aim of pervasive computing is to provide computing technology that is 'smart' and inobtrusive, that supports the way in which we live our daily lives. So, your phone might connect to your fridge, which provides you with useful information – for example, you receive a message when a specific food item has gone out of date. Pervasive computing connects devices, providing information, improving our day to day experiences and increasing the usability of these devices.

WHAT ARE SOME EXAMPLES OF LARGE-SCALE PERVASIVE COMPUTING?

The ways in which we map weather can be thought of as pervasive computing: we use sensors, weather stations and satellites to acquire information about temperature, pressure and humidity. The data can also be used to visualise weather maps that make it easy for us to understand. By compiling data from hundreds of sensors, we can better understand the world, such as the fact that the climate is changing and the Earth is getting hotter.

HOW HAS ELENA USED PERVASIVE COMPUTING IN HER STUDIES?

The technologies that Elena and her team have used in the HEED project have helped them find stories in the data they have gathered. This data can be transferred into actionable information and knowledge that can change the world for the better. The area of pervasive computing is growing at a fast rate, which is leading to an increase in discoveries and innovation, and artificial intelligence is accelerating the rate even further.

IN WHAT WAYS WILL INTERNET OF THINGS (IOT) SYSTEMS IMPACT ON ENERGY USE IN THE FUTURE?

As HEED has shown, the IoT is already making positive contributions to the ways energy use is understood in the displaced context and helping to overcome problems relating to energy poverty in communities around the world. As more and more research is conducted and technology advances, pervasive computing could inform the way energy systems are designed and may one day lead to a world where everybody has access to the electricity and other forms of energy they need for heating, lighting and cooking.

HOW TO BECOME AN ENGINEER

- Much of what Elena does is rooted in sustainable engineering, which involves designing and operating systems that use energy and resources sustainably. The Engineering Council has written a document entitled Guidance on Sustainability for the Engineering Profession. It is well worth reading!
- To understand engineering more broadly, take a look at the Engineering and Physical Sciences Research Council (EPSRC) to get a better feel for some of the engineering opportunities out there.
- Humanitarian engineering involves integrating science and engineering with approaches from social sciences, law, health and medicine, management, business and economics.
- According to Target Careers, graduate engineers can expect a starting salary from £18,000 to £35,000.

PATHWAY FROM SCHOOL TO ENGINEERING AND COMPUTING

Elena highly recommends studying basic sciences, including maths and physics or chemistry, at school and college to give you a good grounding in the subjects before you go to university. The fields of engineering and computing are so broad that it is recommended that you research the specific areas you are thinking of studying to get a better idea of what to study.

To become an electrical engineer, you can do a degree in either electrical or electronic engineering. However, you can also study electromechanical engineering, applied physics or mechatronics. You can find out more here: https://nationalcareers.service.gov.uk/job-profiles/electrical-engineer.

If you are specifically interested in computing, then there is loads of information on the National Careers Service website, which lists a broad range of different careers under the computing, technology and digital banner. You can find out more here: https://nationalcareers.service.gov.uk/job-categories/computing-technology-and-digital.

It is worth remembering that engineering is no longer a single-track discipline. "Engineers need to master a range of skills, including those from computing and computer sciences, as well as social sciences," explains Elena. "This is vital if you want to engineer products that help solve economic and societal problems around the world."

HOW DID PROFESSOR ELENA GAURA BECOME AN ENGINEER?

WHAT INTERESTS DID YOU HAVE AS A CHILD?

I have always been interested in maths and building things. As a child, my interest in these subjects was useful in specific contexts, such as building doll's furniture with wood and nails!

DID YOU ALWAYS KNOW YOU WANTED TO GET INTO ELECTRICAL ENGINEERING?

My father was a field engineer and led the building of large power stations around Romania, where I was born. It always fascinated me, and no doubt propelled me into the field of engineering. However, as a girl, the only branch of engineering that was accessible was electronics, which I pursued with a passion borne from maths, physics and making things works.

WHAT HAS BEEN YOUR PROUDEST MOMENT SO FAR?

Seeing many of the 200 women scientists I trained in India for more than three years succeed against the odds in a male-dominated STEM world.

ARE THERE ANY AMBITIONS YOU STILL WANT TO ACHIEVE?

Yes! I am constantly working on developing a deeper and better understanding of people and how the technologies of the future can work for them!

ELENA'S TOP TIPS

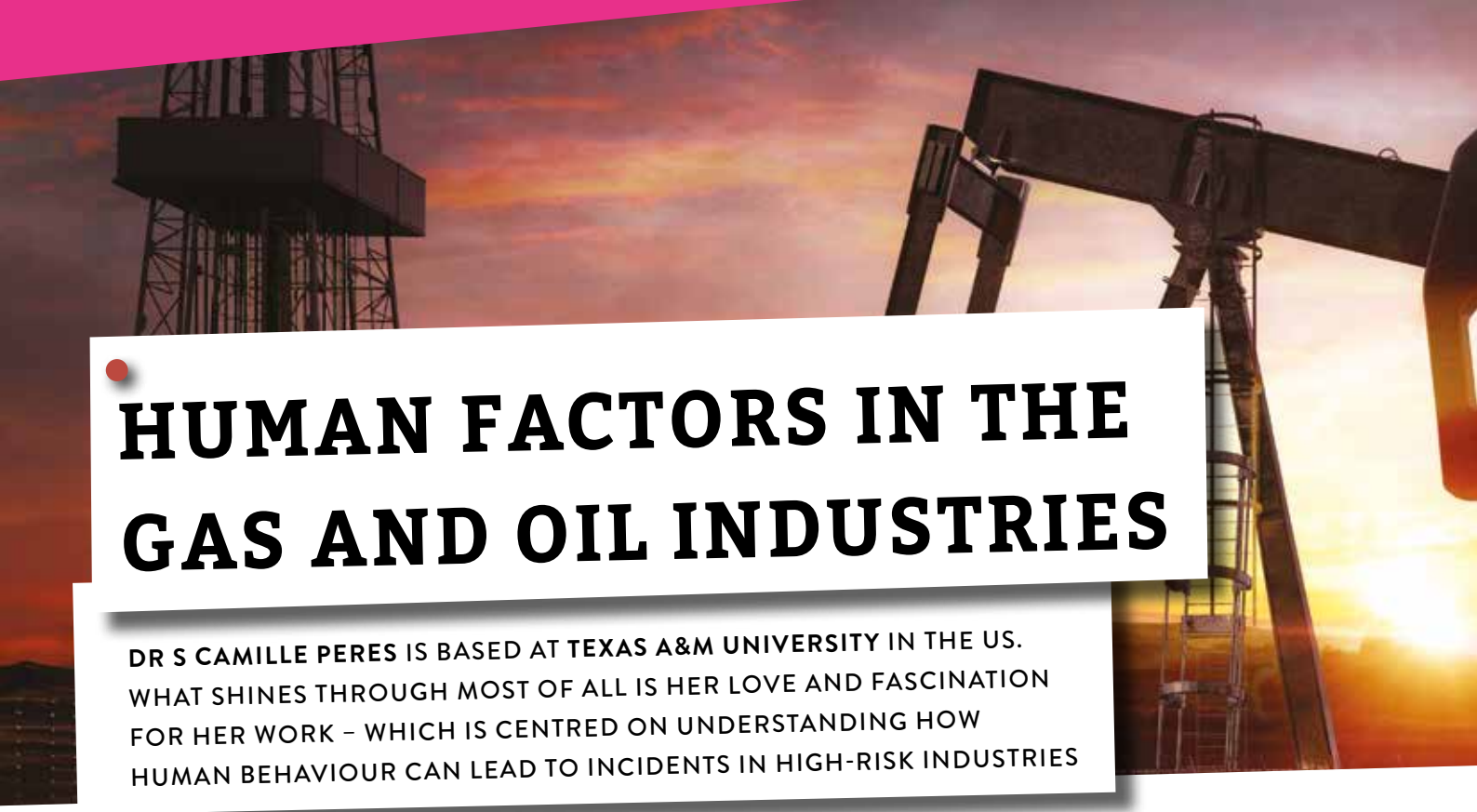
1. If you want to become involved in the field of engineering, then a stronghold in basic sciences, such as maths, physics and chemistry, is a must. However, being widely read in humanities, social sciences, sociology and anthropology will be rewarding too. It will help you understand the purpose of technology in news ways and help you become a better innovator.

2. I think it is so important that women know they have so much more to give to the world. Without women, without their compassion, intuition, perseverance, dedication and pride, the sciences would not be the same. Remember that at all times throughout your career!

3. Listen to the world around you. You must observe it to understand it and by questioning the world, you will be in a position to make it better by engineering the systems of tomorrow!

Recharging mobile phones: *Providing sockets at the community hall means refugees can recharge their mobile phones for free (Nyabiheke, Rwanda).*

Solar street power: *Shrisha recharging her mobile phone using the sockets embedded in a solar street light (Khalte, Nepal).*



HUMAN FACTORS IN THE GAS AND OIL INDUSTRIES

DR S CAMILLE PERES IS BASED AT **TEXAS A&M UNIVERSITY** IN THE US. WHAT SHINES THROUGH MOST OF ALL IS HER LOVE AND FASCINATION FOR HER WORK – WHICH IS CENTRED ON UNDERSTANDING HOW HUMAN BEHAVIOUR CAN LEAD TO INCIDENTS IN HIGH-RISK INDUSTRIES

The Deepwater Horizon oil spill was an industrial disaster that occurred just over a decade ago. It is thought to be the biggest marine oil spill in history and one of the most catastrophic environmental disasters that has ever happened in American history. In the aftermath of the disaster, researchers from a range of scientific disciplines and across industries worked to understand the reasons for the accident, in the hope that something like this would never happen again.

The petrochemical, oil and gas industries have long been known as high-risk, not least because of the potential volatility of the materials involved and the complexity of the work involved. Human factors can also play a significant role and Dr S Camille Peres, based at Texas A&M University in the USA, is working on understanding those factors. One of the main focuses of Camille's research is how human behaviour can lead to incidents such as the Deepwater Horizon oil spill and she has produced a report that finds a link between procedural issues and these incidents.

WHAT ARE THESE PROCEDURAL-RELATED ISSUES AND HOW COMMON ARE THEY?

The damage caused by the Deepwater Horizon oil spill is almost unimaginable and Camille has found that procedural issues are a significant cause of such incidents. "Some of the interesting things we are finding are that the issues workers tell us about are very different to the issues their bosses think they are experiencing," explains Camille. "For instance, workers tell us it's very hard to correct incorrect procedures in a timely manner." It is clear those with the knowledge that something is wrong cannot significantly influence making it right, at least not quickly. In addition, Camille has found that more experienced workers tend to ignore some of the procedures and may be more likely to make a careless mistake.

WHAT IS THE INTERACTIVE BEHAVIOUR TRIAD?

The Interactive Behaviour Triad is a way of looking at the entire system, where people are doing tasks or work so Camille and her team can better understand and predict how people might behave. "As the name suggests, the Triad consists of three elements: the person, the task and the context," says Camille. "We can use the information about these three aspects to predict which tool or method a person will use, depending on their specific circumstance."

One of Camille's favourite examples of this is a piano staircase in Toronto, Canada. Within the Triad, the task is to get from one floor to other (either up or down). There are some hazards because people could fall, but the chances of that are low. The people involved are of various ages, some may be in a rush, while others may be elderly and go slower. The context is that it could be the end of the day, when people are tired, but it could also be the start of the day when people are running late. Importantly, there are two distinct 'tools' to accomplish the task of getting from one floor to the other – the escalator or the piano stairs (which make a noise when anyone steps on them).

The predictions that come from this particular Interactive Behaviour Triad might be three-fold:

- If someone is feeble and less confident in his/her ability to go up and down stairs, that person will probably take the escalator to reduce the risk of falling on the stairs (even though he or she may have wanted to go on the piano stairs).
- If someone is physically able, but has a headache, they might go on the escalator to avoid the noise (and possibly frown at those who use the piano stairs).
- If someone is physically able and on his/her way to work, even if he or she doesn't normally take the stairs, this person might decide to in this instance because these stairs make them smile.

From this, we can see how by analysing the systems or procedures in place, it is possible to predict which option an individual will take. This can be extracted and applied to industry procedures, to maximise the chances that safety guidelines will be followed.

WHY DID CAMILLE CHOOSE TO CONDUCT INTERVIEWS WITH THE WORKERS?

Put simply, it is easier to obtain richer information from conducting interviews.

DR S CAMILLE PERES

Public Health, Texas A&M University, USA

FIELD OF RESEARCH

Human Factors and Ergonomics

RESEARCH

Camille's research is focused on understanding how issues related to procedure are linked to incidents in high-risk industries, such as petrochemical, oil and gas.

FUNDERS

National Science Foundation, National Institute of Health, Next Generation Advanced Procedures Consortium, Texas A&M University School of Public Health

If you ask people to complete a survey or participate in an experiment, there is a two-dimensional aspect to the information. That is not to say it is not useful, but interviewing people can help the team discover information they might not have even considered. "In one interview, a very experienced worker told us that because he has a lot of experience, people ask him a lot of questions – which is a good thing!" says Camille. "However, it also means he gets interrupted a lot and we know from research that interruptions can cause people to make mistakes."

WHAT HAVE BEEN THE KEY FINDINGS AND RECOMMENDATIONS FROM CAMILLE'S STUDY?

Camille's research highlights how a worker's experience and the frequency of the tasks they are asked to perform influences the chances of a procedure being followed. After performing the same task multiple times, a worker will often start acting on instinct and 'tune out'. It is difficult to overcome this problem; often, a person's instincts make them a very good worker, so a balance needs to be found.

The main recommendation from the study is that companies need to start using digital procedures so they can be presented differently depending on the situation. "One example concerns less experienced workers, who are likely to need more information than their more experienced colleagues," says Camille. "We are currently writing grants to develop procedures that will automatically adapt to the work and the worker's situation."

Ultimately, having procedures in place is essential to ensure the safety of the workers and minimise the chances of incidents.

Camille's research acknowledges this but also focuses on what needs to happen to encourage people to follow procedures. The best chance of achieving this is to understand what affects whether a person follows a procedure and then to accommodate those reasons in the way procedures are written and presented.

ABOUT HUMAN FACTORS

Sometimes referred to as an ergonomist, Camille is an expert in human factors. The focus of her studies is on the safety and efficiency of systems and procedures, which also involves understanding human behaviour. As such, her work encompasses a wide range of different fields of enquiry, including psychology, technology and design. Having spoken with Camille, one thing that stands out above anything else is her passion and deep love for her work.

WHAT DOES CAMILLE FIND MOST REWARDING ABOUT HER WORK?

"I have always loved three things in particular about my work," explains Camille. "Helping people, playing with technology and conducting research. In the field of human factors, I get to combine all three things and it is so much fun!"

WHAT ADVICE WOULD CAMILLE OFFER YOUNG WOMEN ENTERING THE FIELD?

Much of Camille's research has been conducted in typically male-oriented industries. One example of this is that the studies detailed above involved interviews with male personnel only. So, it was interesting to speak with Camille about whether she has any advice to give to young women thinking about embarking on a career in human factors. "Surround yourself with positive, strong female advocates. Even if they're not in your field of study, having them around you regularly will give you examples of what it looks like to be a strong, positive woman," says Camille. "Know that when someone questions whether you're capable because you're a woman, it's THEIR issue, not yours. Shoulders back, chin up and charge forward!" We could not agree more.

WHAT IS THE MOST PRESSING ISSUE IN THE CURRENT STUDIES OF HUMAN FACTORS AND WHERE WILL CAMILLE'S RESEARCH GO IN THE FUTURE?

The most pressing thing is probably the constant adjustment to new technology in the workplace. This can make it challenging to determine how to be safe and effective with new technology, as this is not always considered in the development of it. As for her own research, Camille says she sees herself continuing to explore how to better integrate attributes of humans into the complex systems of refineries, chemical plants, oil rigs, etc.

HOW TO BECOME INVOLVED IN HUMAN FACTORS

• Camille says those who are interested in working in human factors should apply to a university that has a dedicated human factors programme. There is a list on the Human Factors and Ergonomics Society website: http://www.hfes.org/

• There is also a tremendous number of resources on the HFES site dedicated to those preparing for a career in human factors and ergonomics: https://www.hfes.org/publications/free-publications/preparing-for-a-career-in-human-factorsergonomics-a-resource-guide

• According to Prospects, entry level ergonomists in the UK can earn between £19,000 to £27,000. With experience, this salary rises to between £35,000 to £65,000. https://www.prospects.ac.uk/job-profiles/ergonomist

• According to Salary.com, the average salary for an ergonomist in America is $75,000. Camille explains that salaries can depend on whether you have a BA or MA, as well as experience. https://www.salary.com/research/salary/posting/ergonomist-salary

PATHWAY FROM SCHOOL TO HUMAN FACTORS

2 or 3 A levels, or equivalent.

You can qualify as an ergonomist by doing a degree in ergonomics, but there is also a range of degrees in related subjects, including design engineering, psychology and occupational therapy.

https://www.prospects.ac.uk/job-profiles/ergonomist

Camille, learning about how chemicals are used to make plastics.

HOW DID DR S CAMILLE PERES BECOME A HUMAN FACTORS RESEARCHER?

WHAT INTERESTS DID YOU HAVE AS A CHILD?

I was interested in pretty much everything! I definitely enjoyed maths and science the most in school. History was always difficult to me because there was so much memorising of facts and figures involved, whereas I much preferred working out problems. I absolutely loved reading as a child – being taken away to another world and place in my imagination by the book was just magical. I have always loved all kinds of art – a passion that was developed by my grandmother – and I really enjoyed my time in technical theatre, but, as I got older, I found myself continuing to be drawn to all things technological – not necessarily how to build them but how to use them.

YOU STUDIED TECHNICAL THEATRE BEFORE PSYCHOLOGY. WHAT INSPIRED YOU TO TAKE THIS CHANGE IN DIRECTION?

The honest answer is the logistics of the situation. I didn't want to work in the evenings all the time. I love technical theatre and working with technology, artists and people, and I really loved the performances. Having said all of that, I don't know that I loved it as much as I love what I do now though, so I feel like I made the right choice.

HOW DO YOU OVERCOME OBSTACLES?

If my current approach to a problem is not working, I talk to people I trust and get advice from them about what I need to do differently. Mostly, I just continue and know that if it's worth it to me, I'm going to continue until I'm successful.

IF YOU HAD TO DESCRIBE YOURSELF IN THREE WORDS, WHAT WOULD THOSE WORDS BE?

Intelligent, interested and caring.

FINALLY, WHAT NON-WORK GOAL IS AT THE TOP OF YOUR 'BUCKET LIST'?

I would really love to fly in a glider someday. It's just something that has always appealed to me!

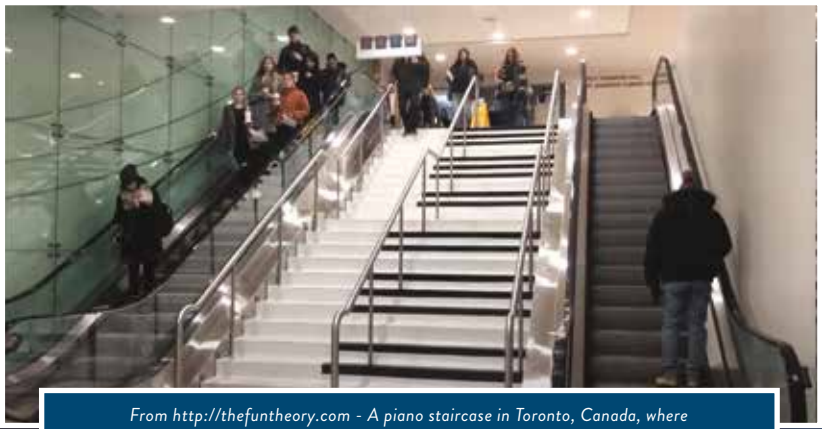
CAMILLE'S TOP TIPS

1 I truly believe that young people should follow their head and heart when trying to find their passion. Sometimes it can take a while (I was in my early 30s) but it is worth it in the end.

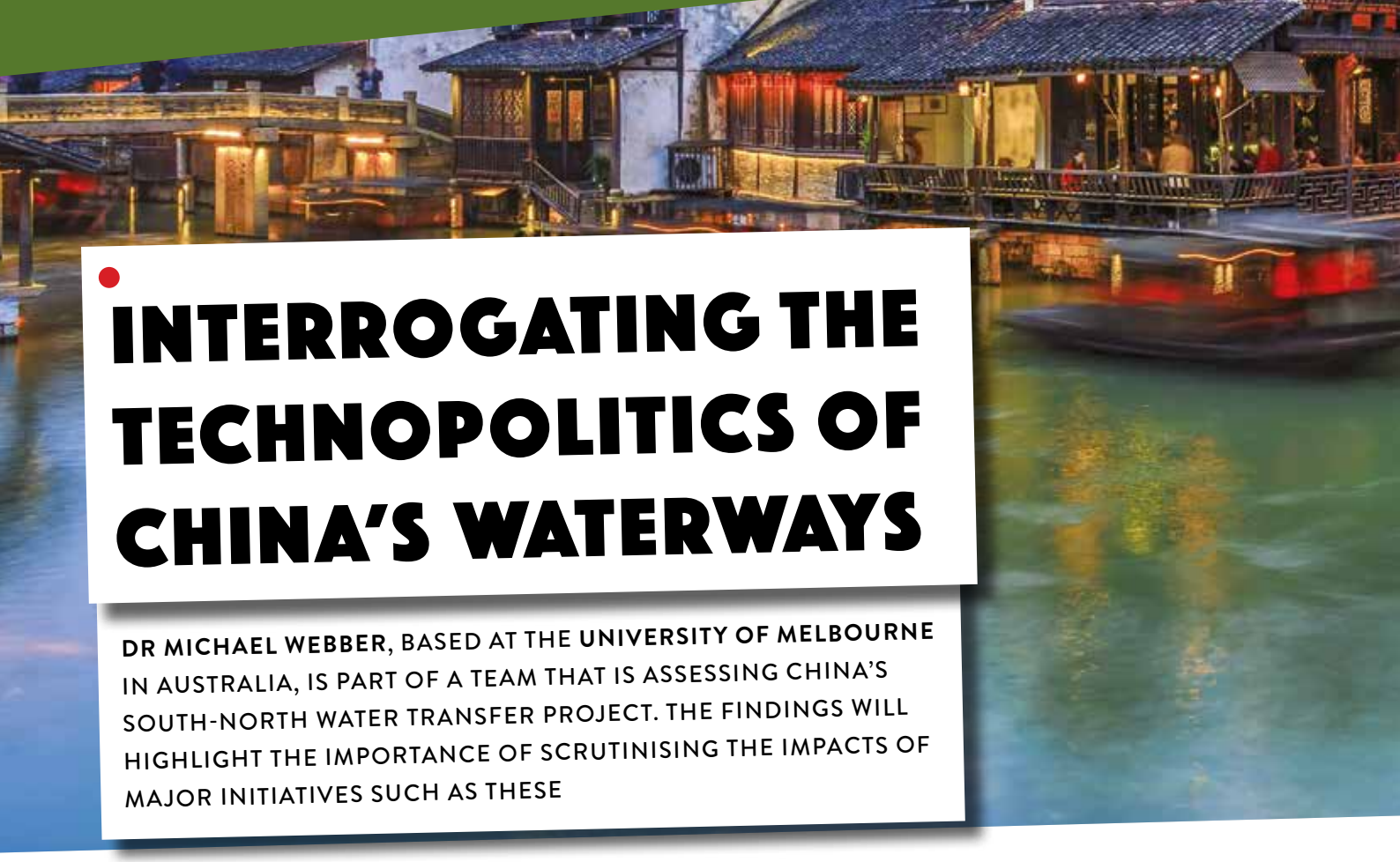
2 It is an amazing feeling to love your job, so work hard and pay attention to the things you like – and don't like – about the tasks you are performing. Over time, your scope of interest will narrow to the point where the path becomes clearer. That's not to say that your work won't be hard and frustrating at times, but it will be worth it!

3 Trust your instincts. If you think a situation is not the way it should be, take a step back and examine it more from a safe perspective. This is especially true for young women entering into the field.

Camille and her students, Trent Parker and Changwon Son, suited up for safety! The team conducted observations and interviews with workers while they performed tasks, while the workers wore cameras on their hardhats to record their work.



From http://thefuntheory.com - A piano staircase in Toronto, Canada, where people can choose how they get from one floor to another.



INTERROGATING THE TECHNOPOLITICS OF CHINA'S WATERWAYS

DR MICHAEL WEBBER, BASED AT THE **UNIVERSITY OF MELBOURNE** IN AUSTRALIA, IS PART OF A TEAM THAT IS ASSESSING CHINA'S SOUTH-NORTH WATER TRANSFER PROJECT. THE FINDINGS WILL HIGHLIGHT THE IMPORTANCE OF SCRUTINISING THE IMPACTS OF MAJOR INITIATIVES SUCH AS THESE

The South-North Water Transfer (SNWT) Project is one of the most ambitious and expensive engineering projects that has ever been conceived. The ultimate aim of the project is to divert 44.8 billion cubic metres of water per year from the Yangtze River in southern China to the Yellow River Basin in northern China, in a bid to ensure that there is more water for industries and cities in the north.

But at what cost? It is said that hundreds of thousands of people will be displaced by the project, with an estimated 330,000 people being relocated for the expansion of the Danjiangkou Reservoir. Then we might ask what the environmental costs of a project such as this are. China is an unimaginably large country. It is home to almost 1.4 billion people and covers approximately 9.6 million square kilometres, making it one of the world's largest countries by area. Diverting water from the south to the north is a serious undertaking and a team of researchers have set about interrogating the socio-economic, environmental and political implications of the project.

WHY IS THE SNWT PROJECT SO INTERESTING TO THE TEAM?

Dr Michael Webber is a geographer based at the University of Melbourne in Australia. He leads the team analysing the SNWT project – research that forms part of a bigger ambition of his. For the past 25 years, Michael has been studying the ways the modernisation of China has changed everyday life there and, as a geographer, he wants to document how big changes in the way we organise societies affect the lives of ordinary people. His approach to this quest is armed with several key ideas. "It is a fundamental fact of geography that the ways in which societies are organised are different in different places," says Michael. "Then there is the fact that societies aren't just people – they are an interaction between people, institutions and environments. Finally, I think of scale – the pathways through which big changes filter down to the opportunity for a new job here, or the loss of a farm there."

The SNWT project brings all of these key ideas together, making it the perfect topic of enquiry for Michael and his team.

HOW DOES TECHNOPOLITICS FILTER THROUGH TO MICHAEL'S RESEARCH?

That the SNWT project has been given the go-ahead is a technopolitical decision – it uses technology in ways that are designed or used to constitute, embody or enact political goals. "Technical water management choices in China are influenced by current political-economic forces, but also constrained by technical choices inherited from the past, and to some extent promoted by international actors," says Michael. "Engineered infrastructures, while 'thick' with politics, are only one element of a broader techno-political water management regime comprised of linked sets of people, engineering, and industrial practices, technological artefacts, political programmes, and institutional ideologies."

WHAT CHALLENGES DOES THIS PROJECT POSE FOR MICHAEL?

One of the key elements of Michael's project is to link decisions made at the level of the central government in Beijing to actions and decisions made by local governments, and on to what happens to the lives of local people, in Beijing and along the routes taken by the project. Michael has learned Mandarin so that he is able to read the necessary documents, find the required data about social and biophysical processes, talk to appropriate officials, and meet with ordinary people. "A lot depends on our physical presence in the field, talking to officials, factory managers and farmers," explains Michael. "Doing this kind of research is not easy – we need an official organisation in China to sponsor us; we need an easy familiarity with living and working in China; we need to be able to communicate in the official language and in local dialects; we need to be able to spend hours walking around villages in the sun, talking to people; we have to arrange transport to get around."

WHAT ARE THE KEY SOCIO-ECONOMIC, ENVIRONMENTAL AND POLITICAL IMPLICATIONS OF THIS PROJECT?

Michael is keen to emphasise how the project reflects the distribution of power in China, that the central government has greater capacity to invest billions in an infrastructure scheme than to reform water management systems in which local jurisdictions have a high degree of local autonomy and little incentive to manage water

DR MICHAEL WEBBER

School of Geography, The University of Melbourne, Australia

FIELD OF RESEARCH

Geography

RESEARCH

Michael's research is concerned with analysing China's South-North Water Transfer Project with several key ideas in mind. The findings highlight the need to interrogate the socio-economic, environmental and political implications of such projects.

FUNDER

ARC Discovery Project, entitled The Technopolitics of China's South-North Water Transfer Project (DP170104138).

at the expense of jobs. The project is consistent with a model of growth that came about in the 1990s and 2000s, that was dominated by investment, including central government-led investment.

Substantial changes in the management of water resources are happening in China which is a cause for alarm – diverting water from the south to the north to support industries and cities sounds like a positive idea at first glance. But you have to ask yourself: from whom is the water being diverted?

EXPERIENCE OF A PHD STUDENT

Hong Jiang is a PhD student who works with Michael as a research assistant. Her PhD project is focused on the geomorphic changes in the Han River channel and its floodplain.

WHAT HAVE YOU GAINED FROM WORKING ON THIS PROJECT?

By collaborating and meeting regularly with other team members in this project, my research interests have expanded into the livelihood and management field, from my initial starting point as a typical physical geographer. My experiences in this project have pushed me to think across disciplinary boundaries.

WHERE DO YOU SEE YOUR CAREER LEADING?

My career plan is to work as a researcher in a water-related field in universities or international research institutes. My special interests are environmental changes and the impact the process of river-related resource exploitation and management has on local community livelihood.

WHAT AMBITIONS DO YOU HAVE FOR THE FUTURE?

From a research perspective, I hope to apply more cross-disciplinary cooperation in future research projects. My ambition is to promote the Land-Trust Nature Reserve Paradigm and contribute to its implementation in more places.

ABOUT GEOGRAPHY

Eratosthenes coined the term 'geography' (albeit in Greek). He was the first person to measure the size of Earth (as far as the details are known) and correctly assumed that the Sun's distance from our planet was rather large. Since then, geography has developed significantly and is rightly recognised as a field of study that crosses the boundaries of science and social science/humanities. As such, it offers students virtually boundless opportunities. No single career can be said to be the natural product of a geography degree. Instead, it is often thought of as the foundation of something more nuanced.

HOW IMPORTANT IS COLLABORATION IN GEOGRAPHY?

Vital. "I need to be able to work with people who are experts in social science and the more social aspects of geography, as well as with people who are experts in the biophysical environment and engineering," explains Michael. "Then, too, we need people who have more general knowledge about the specific place we are working in. An understanding of where we are, how we got here, and what we should do about the future demands that we bring together all these skills."

There is also the fact that people in different disciplines approach problems from different mindsets – all bring fresh perspectives that are essential to overcoming challenges; some disciplines look more for deeper understanding, whereas others seek ways to build on what we know.

WHAT ARE THE MOST PRESSING ISSUES FACING TODAY'S GEOGRAPHERS?

The most pressing issues facing geographers are arguably those facing the rest of the world – environmental changes and inequality. "Geographers are among a host of disciplines and individual scientists who are studying these issues," says Michael. "We bring an understanding of integrated social-environmental-technological systems that are different in different places and that are linked in a scalar network of causes and effects."

HOW TO BECOME A GEOGRAPHER

- The Geography Site brings together a wide range of academic geographical organisations that will provide you with a massive amount of useful information. **www.geography-site.co.uk**
- The National Committee for Geographical Sciences aims to foster geography in Australia. **www.science.org.au**
- The average salary for a geographer is AUS $115,265, depending on experience. Entry level geographers can expect around AUS $81,276 while those at senior level can expect AUS $143,174. **www.salaryexpert.com/salary/job/geographer/australia**

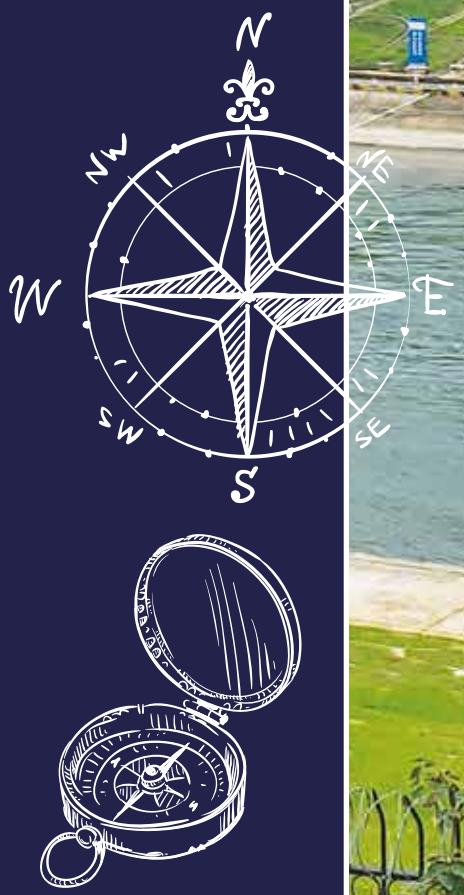
PATHWAY FROM SCHOOL TO GEOGRAPHY

Michael is unequivocal about doing the subjects you are interested in and are relatively good at (although being interested in subjects is often the first means of being good at them). "Geographers can supplement their core geographic studies with subjects like economics (which is what I did), sociology, politics, chemistry, geology, meteorology or biology – depending on what kind of geography they are most interested in," explains Michael. "A second language is always helpful too."

2 or 3 A levels, or equivalent.

A geography degree is one possibility, but that will open doors to so many different careers, including landscape architect, environmental manager, cartographer and transport planner. As a classic generalist degree, a geography qualification really does mean the world is your oyster!

www.prospects.ac.uk/careers-advice/what-can-i-do-with-my-degree/geography



HOW DID DR MICHAEL WEBBER BECOME A GEOGRAPHER?

WHAT WERE YOUR INTERESTS AS A CHILD?

I was interested in sport, particularly rugby and cricket, but there was a range of subjects that I enjoyed too. I was most interested in geography, history and biology, although I wasn't too good at biology!

WHO OR WHAT HAS INSPIRED YOU IN YOUR CAREER?

I grew up in two different environments – in a coal-mining town in South Wales and later in a small town in the west of England. The contrast between these two, in terms of my life and the lives of adults, was profound – the dangers of work, the amount of open space, the population density, the standards of living and the life chances of kids were all so different. It was almost like being in two different countries. I also had a great geography teacher at school, who just happened to be my mother!

WHAT HAVE BEEN SOME OF YOUR PROUDEST ACHIEVEMENTS?

I have written what I think are two or three really good books. I have also supervised some excellent PhD students, which makes me proud. Then there is the fact I have led some elegantly designed and well-executed research projects.

HOW DO YOU OVERCOME OBSTACLES IN YOUR WORK?

Seek help and listen. It took me a long time to learn to do this – but listen to all the advice you can get from as many sources as possible, and then try to make a decision that reflects the best advice and your own goals. Persistence is key too – some things are just difficult and require time and effort to get them done. Learning Chinese is one of those tasks – it is a daily commitment, demanding an hour or two every day, no matter what else has to be done. Thankfully, I have got to the level where I can read enough to do the work I need to do!

WHAT GOALS DO YOU HAVE LEFT TO ACHIEVE?

I aim to supervise my existing PhD students to do the best they can and also lead this project to the best of my ability. I hope to publish useful contributions to knowledge about the China's South-North Water Transfer Project and about ways of understanding similar projects.

MICHAEL'S TOP TIPS

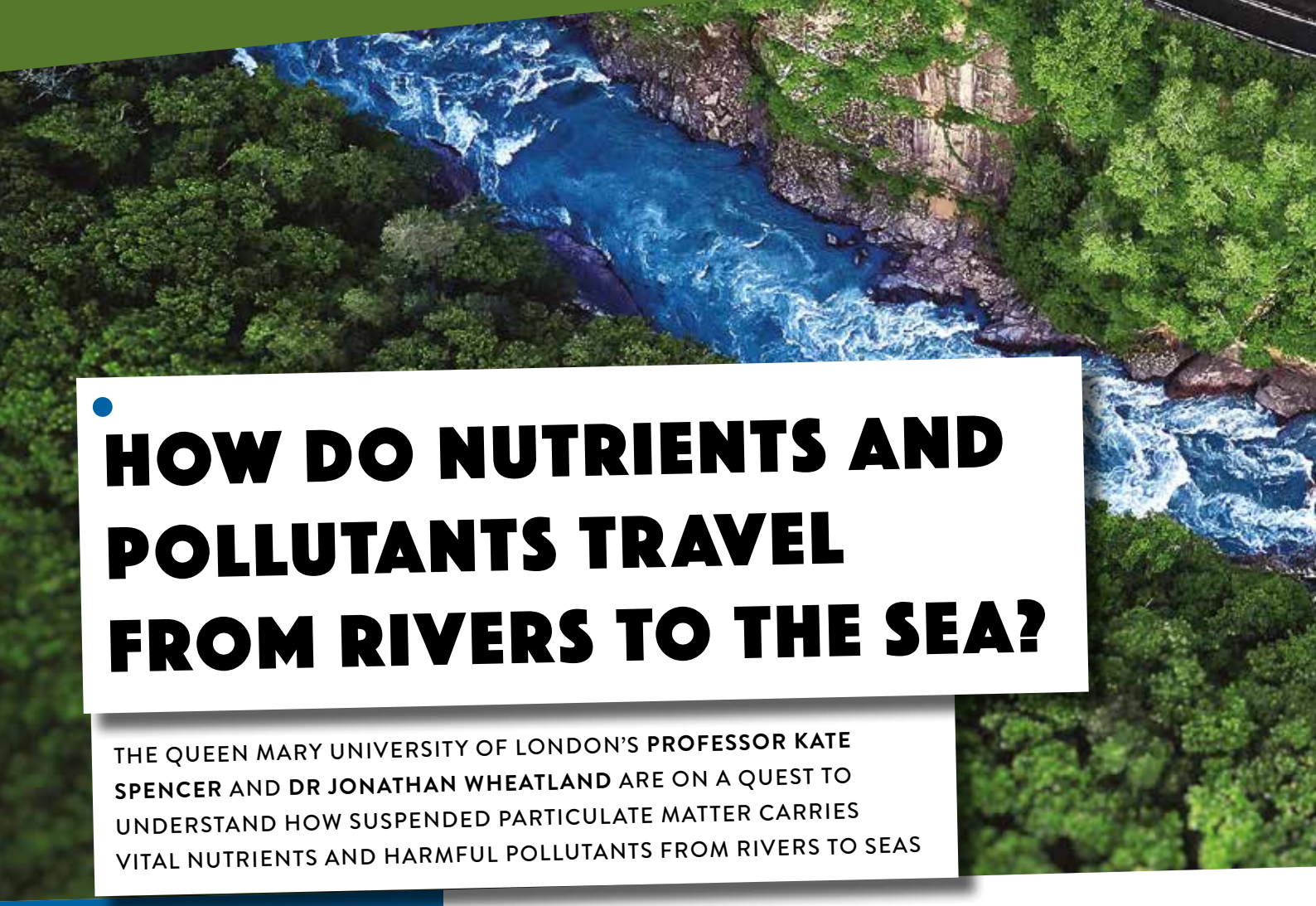
1. Enjoy yourself! If you are going to work within a specific field – whatever it is – you are going to spend a lot of time doing it. If you don't enjoy it and don't think you are making a valuable contribution, you are going to spend a good part of your life feeling ordinary at best and, perhaps, even miserable.

2. Find an environment where you can do what you like best about your specialty. Do you like doing research? Then look for a university, research institute or company where you can advance your career while still doing research. Do you like applying the research that you find out about? Then look for places, like planning or environment departments, where you can do that. Do you like the idea of managing projects and people? Then look for organisations where you spend some time researching or applying research before entering a more management-oriented track.

3. If you like communicating current ideas and research in geography, then a career in journalism or teaching might be for you.

On the Yangtze River Conservancy Commission's boat, Danjiangkou Reservoir. Photo by ZHAO Yue

Talking to an official from the Yangtze River Conservancy Commission. From the left: the official, Professor Wang [partially hidden], me, Dr Lamb, Dr Jiang, Professor Rutherfurd, Dr Rogers, another official. Photo by ZHAO Yue



HOW DO NUTRIENTS AND POLLUTANTS TRAVEL FROM RIVERS TO THE SEA?

THE QUEEN MARY UNIVERSITY OF LONDON'S **PROFESSOR KATE SPENCER** AND **DR JONATHAN WHEATLAND** ARE ON A QUEST TO UNDERSTAND HOW SUSPENDED PARTICULATE MATTER CARRIES VITAL NUTRIENTS AND HARMFUL POLLUTANTS FROM RIVERS TO SEAS

TALK LIKE AN ENVIRONMENTAL SCIENTIST

Sediment – a naturally occurring material that settles to the bottom of a liquid

Pollutant – a substance that pollutes something and causes harm, especially to soil, water or the atmosphere

Pathogen – a bacterium, virus or other microorganism that can cause disease

Nutrient – a substance used by an organism to survive, grow and reproduce

Aggregate – a collection of particles that form a mass

Suspended particulate matter (SPM) – nanoscale to sand-size particles that are suspended in the water column of streams, rivers and lakes

Suspended particulate matter (SPM) is composed of incredibly small particles of solid matter that are suspended in the water. This matter can include fine grained mineral sediment, such as clay and silt, as well as organic matter from decaying plants and microbes. A high concentration of SPM is major cause of poor water quality and can affect aquatic wildlife.

The components that come together to create SPM are incredibly small. They generally measure between 10 and 1000 microns across (1000 microns is 1 millimetre). When they come together, they form loose, fragile aggregates that are sometimes called 'flocs'. These aggregates are porous, which means they contain a lot of fluid-filled space.

Because SPM has a density that is similar to water, it can be easily suspended by water and travel immense distances. As it does, it carries important nutrients and sediments from rivers into the sea.

WHAT IS IT ABOUT SPM THAT IS OF INTEREST?

While the nutrients and sediments carried from rivers into the sea help sustain marine life, SPM can also contain pollutants, pathogens and even microplastics, which can be harmful. It is therefore important to understand more about SPM, including shape, size, structure and composition. Scientists want to know the mechanisms behind SPM to better understand the impact it has on ecosystems.

The Queen Mary University of London's (QMUL's) Professor Kate Spencer and Dr Jonathan Wheatland form part of a group that is attempting to develop our understanding of SPM. While many researchers have studied SPM, Kate and Jonathan have approached the subject from a unique perspective. "What is unique about our work is that we can capture these natural and complex aggregates and preserve their fragile structure," explains Kate. "We can also look at scales from a few millimetres down to nanometres meaning we can examine everything from their overall size and shape, to the individual bacteria and clay minerals they contain."

WHAT IS IMPORTANT ABOUT KATE AND JONATHAN'S RESEARCH?

The presence of SPM is essential to the healthy functioning of aquatic ecosystems. However, too much SPM can damage habitats and can lead to higher water treatment costs. Kate and Jonathan want to understand and predict how it moves through the water and where it finally settles. "Many water bodies are naturally very muddy. For example, estuaries contain large amounts of SPM, which is why our big rivers often look brown and dirty," explains Kate. "However, poor land management practices, such as deforestation or the drainage of upland wetlands, can result in increased erosion on our hillslopes,

PROFESSOR KATE SPENCER

Professor of Environmental Geochemistry, School of Geography, Queen Mary University of London, UK

DR JONATHAN WHEATLAND

Postdoctoral Research Assistant, School of Geography, Queen Mary University of London, UK

FIELD OF RESEARCH

Environmental Geochemistry

RESEARCH PROJECT

Kate and Jonathan are investigating suspended particulate matter (SPM) and observing it in 3D to see how individual particles interact with each other. Ultimately, they hope to determine the role SPM plays in transporting harmful materials into aquatic ecosystems.

FUNDER

UK Research and Innovation (UKRI)

delivering more particulate material to our rivers."

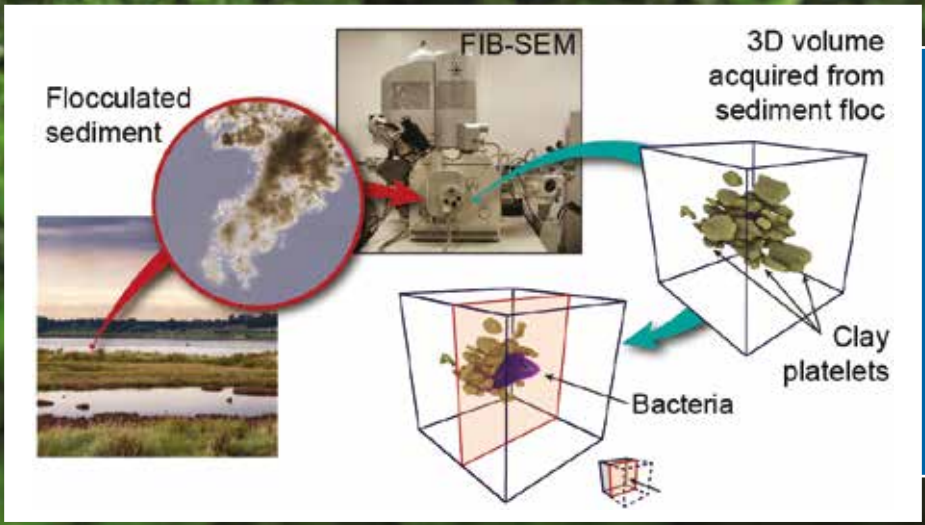
The team wants to understand SPM's composition and whether different types of pollutants or organic matter influence how it behaves in the water column. SPM has very complex shapes and structures, so sampling and analysing it can be very difficult. Other researchers have relied on techniques such as 2D cross sections, but these have produced a limited understanding. Kate and Jonathan are using techniques that will enable them to sample, observe and quantify the micro-structure of SPM in 3D for the first time – this will help to develop our understanding of how SPM moves about and what it contains.

WHERE DID THE IDEA COME FROM TO STUDY SPM USING SAMPLING TECHNIQUES FROM THE BIOMEDICAL SCIENCES?

Environmental and Earth scientists have been using CAT scans (computerised tomography) to look at the internal structure of sediments and soils for years. Kate, Jonathan and the team wanted to know if they could use other, similar techniques to look at much smaller samples and see the fine detail of SPM. So much of successful scientific research is based on collaboration and taking ideas from one field and transplanting them onto another. "Our project is a collaboration between environmental scientists, materials scientists and engineers," says Kate. "We worked closely with our colleagues in QMUL's NanoVision Centre - a state-of-the-art microscope unit - to see what methods we could apply to our research."

WHAT IS KATE'S TEAM HOPING TO ACHIEVE?

It is the first time that anybody anywhere has been able to observe the internal structure of SPM in 3D and see how individual particles interact with each other. Kate and Jonathan hope to use this information to improve their understanding of how SPM is transported. "We want to improve the mathematical models that predict how quickly SPM settles and erodes," says Kate. "In the future, we also hope to use this information to understand how important SPM is for transporting pollutants and carbon through the aquatic environment."



Using nano-tomography (a technique similar to CAT scans, but measuring much smaller samples), Kate and Jonathan can observe the internal structure of SPM in 3D and see how individual particles interact with each other. This image shows a collection of clay particles surrounding a single bacterium (pink). These particles are just a few microns in size.

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ABOUT ENVIRONMENTAL GEOCHEMISTRY

The negative impacts of human activity on the environment continue to be a talking point around the world. As such, the need for the environmental sector to try and ascertain the effects of particular actions is increasingly vital. This perhaps best explains why environmental geochemistry has grown rapidly over the past decade or so.

Environmental geochemistry is primarily concerned with understanding a whole manner of things associated with chemical elements and gases in the surface environment. Such environments might include bodies of water, crops, animals and humans. By understanding how such elements and gases come to be dispersed in such environments – and the effects of these dispersals – preventive measures can be put in place or motivations to act can be scientifically justified.

WHAT SORTS OF THINGS DO ENVIRONMENTAL GEOCHEMISTS STUDY?

"An environmental geochemist studies the abundance, distribution and behaviour of chemicals in the environment that are associated with natural geomaterials such as rocks, soil and sediment," explains Kate. "The topic can be really broad but is extremely important for understanding everything from soil fertility to pollution."

Clearly, there is no single thing that an environmental geochemist studies, but the breadth of topics – and the potential benefits – makes this an especially important field of enquiry, particularly in this day and age. Indeed, Kate's background in environmental geochemistry has enabled her to work on much broader environmental projects such as the SPM imaging project described on pages 1 and 2.

WHAT ARE ENVIRONMENTAL GEOCHEMISTS TRYING TO ACHIEVE IN THEIR WORK?

As with many scientific fields, collaboration can be an essential mode of working, not least because one area of understanding can often be accentuated by combining with another. "Environmental geochemists often work closely with geologists, ecologists, hydrologists, soil scientists and geomorphologists," says Kate. "Environmental geochemists are often trying to understand the impact that human activity has had on the environment, how important this is for ecological and human health, and how to remediate or solve these problems."

Importantly, this is not a topic that is going to diminish in importance, so if you are interested in making a real difference in your career, environmental geochemistry is at the forefront of positive change.

ARE THERE MANY OPPORTUNITIES IN ENVIRONMENTAL GEOCHEMISTRY IN THE UK?

Environmental geochemistry is not a fleeting subject: it is a vital field of enquiry now, but one that will surely only increase in importance as time goes on. As such, whatever opportunities there are today, there are likely to be more tomorrow (metaphorically speaking).

It is also worth bearing in mind that studying one subject, i.e. geochemistry, does not limit you to that one subject. Kate's title may be Professor of Environmental Geochemistry, but she describes herself as an environmental scientist. Kate is based at QMUL's School of Geography and her work is truly interdisciplinary, involving geography, geology and Earth science.

HOW TO BECOME AN ENVIRONMENTAL GEOCHEMIST AND ENVIRONMENTAL SCIENTIST

- The Royal Geographical Society has a Geography Ambassador scheme that recruits, trains and supports undergraduate geographers
- If you are interested in becoming a geochemist, Prospects has a dedicated section of its website which details all of the things you can expect from a career in geochemistry: https://www.prospects.ac.uk/job-profiles/geochemist
- According to The Geological Society, the starting salary for an environmental geochemist is anywhere between £20,000 and £30,000, with more senior positions earning between £32,000 and £50,000

PATHWAY FROM SCHOOL TO GEOCHEMIST/ ENVIRONMENTAL SCIENTIST

2 or 3 A-levels, or equivalent, including chemistry

Relevant degree areas include geography, Earth sciences, geosciences, physical, mathematical and applied sciences, and engineering

https://www.prospects.ac.uk/job-profiles/geochemist

First-year BSc geographers, as part of the East Anglia field class, explored the long-term evolution of the coastline and the River Stour at Stutton Ness.

MEET PROFESSOR KATE SPENCER AND DR JONATHAN WHEATLAND

WHAT DID YOU WANT TO BE WHEN YOU WERE YOUNGER?

KS: I never knew what I wanted to be, but I was always good at science and a very good communicator. I always liked nature and being outdoors – I cared a lot about protecting the environment, even when I was quite young. I did a degree in Earth Science that managed to combine all these skills and interests.

JW: I've always had an interest in understanding why things happen, particularly the processes that occur in the natural world. My fondest childhood memory is fossil hunting along the rugged coastline of Pembrokeshire in Wales – I'm sure at one point I wanted to be a palaeontologist! I ended up pursuing a degree in Geography and am glad I did because it has enabled me to work in some truly spectacular places.

WHO OR WHAT INSPIRED YOU TO BECOME A GEOCHEMIST?

KS: I didn't know it existed as a subject until I was at university. In the final year there was a module called 'Environmental Geochemistry'. I decided to take it and, as they say, the rest is history.

JW: I had very 'outdoorsy' holidays growing up and always wanted to do something related to the Earth Sciences.

KATE, YOUR BACKGROUND IS IN ENVIRONMENTAL GEOCHEMISTRY, BUT YOU ALSO WORK ON MUCH BROADER ENVIRONMENTAL PROJECTS LIKE THE ONE IN THIS ARTICLE. HOW ARE YOU ABLE TO DO THIS?

I've always had a very wide interest in coastal and aquatic environments, meaning that my research has been quite varied. My particular expertise is looking at the behaviour of pollutants and nutrients in the natural environment, but these skills can have many applications. I love working in a geography and environmental science department, because my colleagues and I are always looking for interdisciplinary approaches to understand and solve environmental problems.

IS THERE ANYTHING THAT PARTICULARLY WORRIES YOU ABOUT THE STATE OF OUR PLANET?

KS: I am concerned about how quickly and easily we create new chemicals and products with little understanding of how they behave or their potential impact. Microplastics are a hot topic in the news at the moment, but there are hundreds of new or 'emerging' chemicals that are developed for wide-ranging industrial, medical and even recreational purposes that end up in the environment.

We can develop technologies to remediate and clean up the environment, but we all have a role to play as environmental citizens trying to consume and pollute less.

JW: I worry about how our society's current attitude to the environment seems to be that it is an expendable and infinite resource. Modern life is often disconnected with nature and I think this has led to apathy with regards to its protection. That being said, I do believe that science can help solve the problems we have caused and, with the recent increase in 'environmental awareness', hopefully governments will begin to legislate 'green' policies.

WHAT INSPIRES YOU TO GET UP IN THE MORNING?

KS: Sunshine, conversation, having a long 'to do' list and a hungry cat!

JW: I'm not really a morning person, but if it's sunny and I have a good idea I will often jump straight into my work – maybe after I have had one or two coffees!

IF YOU COULD GO BACK IN TIME AND START YOUR CAREER AGAIN, WHAT WOULD YOU DO DIFFERENTLY?

KS: Probably nothing. I didn't have a plan at the start of my career, but I always felt that what I did was interesting and a lot of fun. I think I was good at spotting opportunities from the outset which has served me well.

JW: That's a difficult question. There are a few things I might have done differently, but I am happy where I am with my career now. If I had to go back, I would perhaps try not to put too much pressure on myself (I am a bit of a worrier).

KATE'S TOP TIPS

1. It is important to gain a broad science background if you are going to embark on a career in geochemistry.
2. If possible, do your best to get an understanding of the natural environment as soon as possible. This will stand you in good stead when studying and it will aid you throughout your career.

JONATHAN'S TOP TIPS

1. Do something you love, no matter what career you end up doing. People forget that what they will be doing for their career will be for the majority of their life, so it is extremely important to prioritise your own happiness and wellbeing.
2. Remember that if you are interested in pursuing a career in science it can be tough, but the rewards you get out of it can be truly amazing. It is worth the hard work.

BRINGING THE EARTH TO LIFE

GEOSCIENCE IS A CHALLENGING SCIENCE TO TEACH. IT INVOLVES PROCESSES THAT OCCUR OVER HUGE SCALES OF TIME AND SPACE, AND MUCH OF ITS SUBJECT MATTER IS DEEP UNDERGROUND. **DR GLENN DOLPHIN**, OF THE **UNIVERSITY OF CALGARY** IN CANADA, IS COMMITTED TO TACKLING THIS CHALLENGE, THROUGH CONNECTING TEACHERS AND STUDENTS WITH AUTHENTIC RESEARCH EXPERIENCES

THE ART OF TEACHING

As you will know, effective teaching and learning is not just about the presenting and memorising of facts. To convey a proper understanding of the world, teaching needs to be engaging, interesting and accessible. What teaching techniques engage you? What makes learning memorable for you? What makes you excited about a subject? What makes you want to learn more?

Geoscience, or Earth science, does not always get the limelight in the same way as other sciences, such as astronomy or ecology. However, it is essential to our understanding of the world, and at the heart of many societal issues. Dr Glenn Dolphin, Tamaratt Teaching Professor in the Department of Geoscience at Canada's University of Calgary, has introduced some novel teaching methods to help geoscience get the recognition it deserves.

GEOSCIENCE'S PUBLIC IMAGE

"Earth science is a very neglected science, and professional Earth scientists are retiring faster than they can be replaced," says Glenn. He believes a key part of this is that it is not always taught effectively, and many students don't see it for the fascinating subject area that it is. Geoscience has a key role in tackling humanity's most pressing problems: climate change, extraction of energy and mineral resources, and access to clean air and water. Glenn is passionate in his belief that geoscience is a subject we should be paying more attention to.

New talented and enthusiastic Earth scientists – and Earth science teachers – are sorely needed. How can Earth science teachers be taught to teach well? "Traditional teaching methods, such as lectures and essays, are not nearly as effective as evidence-based approaches," says Glenn. "This is where the model-based approach and authentic research experiences come in."

MODELS TO UNDERSTAND THE EARTH

What's more engaging: an essay about tectonic plates, or a physical model of them in action? Geoscience is complex, and the processes it studies happen at a far grander scale – in terms of both space and time – than we are accustomed to. To help teach this complexity and make the abstract concepts more approachable, physical and virtual models are an invaluable tool.

For instance, virtual outcrop models are one handy device in this arsenal. They are computer-generated 3D models of real-world rock outcrops. Drones capture hundreds or thousands of images of the physical outcrop from every angle, and the software 'stitches' these images together. Students can then explore these outcrops from the comfort of their computers.

GUIDING TEACHERS

As part of a team of teacher educators, Glenn worked with trainee teachers to address the

DR GLENN DOLPHIN

Tamaratt Teaching Professor
Department of Geoscience
University of Calgary, Canada

FIELD OF RESEARCH

Geoscience Education

RESEARCH PROJECT

Designing and building models to help teachers understand and teach geoscience concepts.

FUNDER

The National Science Foundation

Geologists, drone technicians and national park service personnel hike to the Saskatchewan Glacier in Alberta to collect image data to develop a virtual outcrop model.

concepts that are difficult to teach. Once teachers had selected a concept, they and Glenn's team researched it and built a model to act as a teaching aid. Teachers were enthusiastic about the research and reported they had learnt a lot from the design-and-build process.

They presented these models at a science teachers' conference, where other science educators also found them instructive. Many have also been rolled out to real classrooms, to see how successful they are in making the teaching and learning process easier.

Glenn hopes geoscience teachers "will continue to enhance their learning and teaching by continued research and development of models." However, he wants teachers to be reflective as well as ambitious. He adds, "Hopefully, they will also become critical of models they use as many actually pose problems for learning as well as offer solutions."

DRAMA AND BUILDING

Glenn believes that the intersection between science and the humanities should be embraced to make learning as captivating as possible. "I am currently collaborating with the university's drama department to produce a play about four famous female geologists from different time periods," he says. "It will explore their life histories, their research and the role that gender played in their careers."

He is also working with the architecture department to develop a geological 'time walk'. "It will be a scale model of the history of the Earth, in the form of a path," he says. "People can walk along it and get a sense of the scale of geological time."

Glenn is passionate about looking at the human stories behind science. For him, the history of how scientific knowledge has come to be is as important as the science. Glenn explains, "Demonstrating how science 'fits' into the rest of life provides a broader view of how science emerges from researchers' real lives and real passions."

LOOKING TO THE FUTURE

Glenn hopes that his work will continue to be used by teachers to enhance their knowledge and teaching skills. "These teachers will have contact with thousands of students during their careers," he says. "That is where the big payoff will be. Hopefully, they will bring other teachers along with them on this journey. If others see how successful they are, these teachers become models for future teachers." Inspiring teachers lead to a 'snowballing' change in teaching style.

For the future of geoscience itself, there is a lot of fascinating and important research waiting to be done. There is ample opportunity for entry into the field, especially for those who are passionate about fixing the world's problems.

ABOUT GEOSCIENCE

Geoscience is the study of the Earth. This involves not only geology (the study of rocks), but also our ocean and river systems, the atmosphere, and the processes that interlink them all. Some might be surprised to know that geoscience also includes planetary science – including the study of asteroids and comets.

"Geoscience is like a crime scene that needs investigation," says Glenn. "It goes back 4.6 billion years, and lots of evidence has been removed or changed. The geoscientist's job is to sift through all the evidence, decide what is genuine, and develop a unifying explanation. It's like being a detective, except more difficult because you never know if you have the right answer – you only have the answer that fits the evidence the best."

GEOSCIENCE IN THE REAL WORLD

Geoscience underpins many of the issues we see today. For instance, geoscientists study the atmospheric changes that lead to global warming. They study the mineral and energy resources within the Earth, and the impacts of extracting them. They study the causes and effects of natural disasters like earthquakes and volcanic eruptions. "Geoscience is necessary to preserve the human race," says Glenn.

"I love teaching geoscience, because I learn something new every time," says Glenn. "I love the process of assembling evidence into a story that I can tell students. When I teach, I make it about the scientists themselves and the context of their lives – the social, political and economic pressures at the time that all influence scientific progress. And, most fascinatingly, geoscience can lend insights that change the way we see the world forever."

ADVICE FOR TEACHERS

So how can teachers make sure they are teaching geoscience – and other subjects, for that matter – in the most effective and engaging way possible? "Be bold," says Glenn. "Some books suggest taking small steps in your teaching style, but I find that taking a deep breath and embracing change all at once is most satisfying."

Geoscience may seem quite abstract at first, but it has significant relevance to our daily lives. "I find that students like a narrative, so I tell the stories of how geoscience concepts first developed," says Glenn. "I find most students appreciate that approach, and it helps connect the science to their lives. It also helps students see that scientists are regular people, and more importantly, that regular people can become scientists."

HOW TO BECOME A GEOSCIENTIST

- The American Geosciences Institute (AGI) has a great infographic that explains the broad range of career options related to geosciences: https://www.americangeosciences.org/workforce/workforce-infographic
- According to US News, the best universities for geosciences in Canada are Toronto, British Columbia, Alberta, McGill and Victoria.
- According to UK Uni, the top UK universities for geology are Imperial College London, Cambridge, Oxford, Durham and Bristol.
- Aside from university, there are apprenticeships available in geoscience. Oxford's Department of Earth Sciences and the UK's Environment Agency have taken on apprentices in the past.
- According to Payscale, the average salary for a geologist in Canada is around C$74k per annum.

HOW DID DR GLENN DOLPHIN BECOME A GEOSCIENTIST?

WHAT DID YOU WANT TO BE AS A CHILD?

I have wanted to be a geologist ever since I can remember. As a kid, I would keep pretty rocks in a large milk container and would wash and organise them. I often went to rock and mineral shows, bought crystals, and participated in a local rock and mineral club. I was surrounded by very supportive people, especially my dad and several teachers, who really influenced my trajectory into geology.

WHO INSPIRED YOU IN YOUR CAREER?

I have had many inspirations throughout my life. I had an enthusiastic Earth science teacher in ninth grade, and several professors at my local university helped me decide where to study. I had a great mentor when I then studied to become a teacher, after which I went on to teach at my old high school alongside two of my former teachers. These two people were crucial in helping me develop my teaching style, letting me explore alternative methods and helping me get leadership roles. I then got a PhD in science education, guided by many inspirational figures, and even in my current post I have great colleagues who help support my work.

WHAT CHALLENGES HAVE YOU FACED IN YOUR CAREER?

My toughest personal decision was leaving my daughter in New York when I went to work in Calgary. She was nine at the time and I regret missing many moments of her growing up. Professionally, my greatest challenge is getting more 'traditional' geoscientists to consider this kind of work important. It seems 'fluffy' to them because they don't consider it hard science, and I find it difficult when I feel my work is not valued.

WHAT ATTRIBUTES HAVE HELPED YOU BECOME SUCCESSFUL?

I have a lot of energy and passion for what I do, and students can sense that and become passionate themselves. A thank-you note from a student of mine said, "I am studying to be a teacher and feel so enthused after taking your class. Your passion for teaching and creating inspired, engaged learners is truly motivating."

WHAT ARE YOU MOST PROUD OF?

I am most proud of my family: three wonderful daughters and my wife, who is more than anyone deserves. My second proudest achievement is a textbook I wrote for one of my geology courses: "Stories in Geology: What we know and how we figured it out." This book helps to fill two gaps in science teaching: the 'process of science', and the role of humanities and history in science.

PATHWAY FROM SCHOOL TO GEOSCIENTIST

At school, subjects like physics, maths and chemistry are the most desirable for university applications. Geography, computer science or biology are also favoured by some universities. Degrees in geology, geoscience, geophysics or Earth science can all lead to a geoscience career.

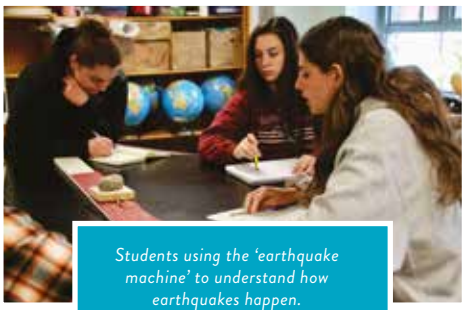
Glenn recommends taking every subject you can, even those outside your comfort zone. As well as maths and science, arts and the humanities play a significant part in research and teaching.

GLENN'S TOP TIPS FOR STUDENTS

01 – Find your passion and embrace it. Take chances and spend as much time as possible outside of your comfort zone.

02 – Use all your accumulated life experience, even chapters you don't like, to make you who you are.

03 - Be bold, but also understand that our lives are shaped by everyone around us. We can influence the direction of our lives but are never in full control. I find this to be very liberating.



Students using the 'earthquake machine' to understand how earthquakes happen.

Technicians collecting image data near Drumheller, Alberta, to create a virtual outcrop model.

MAKE IT RAIN: THE SCIENCE BEHIND ALTERING THE WEATHER

WHENEVER HUMANKIND BELIEVES IT HAS CONTROL OVER THE NATURAL WORLD, THE WEATHER LIKES TO PROVE US WRONG. STORMS, FLOODS AND DROUGHTS ARE JUST SOME OF THE WEATHER PATTERNS THAT CAN COMPLICATE OR EVEN THREATEN HUMAN LIFE. WE HAVE INCREASINGLY SOPHISTICATED TECHNIQUES FOR WEATHER FORECASTING, BUT NOW SCIENTISTS ARE LOOKING EVEN FURTHER: TOWARDS DIRECTLY MODIFYING THE WEATHER ITSELF. **DR DARREL BAUMGARDNER**, OF THE **NATIONAL AUTONOMOUS UNIVERSITY OF MEXICO** AND **DROPLET MEASUREMENT TECHNOLOGIES**, RESEARCHES THE INTRIGUING TECHNIQUE OF CLOUD SEEDING

TALK LIKE AN ATMOSPHERIC SCIENTIST

CLIMATE – the general weather conditions over a long period.

CLOUD CONDENSATION NUCLEI (CCN) – small particles around which water vapour condenses and ultimately forms clouds.

CLOUD SEEDING – intentionally adding CCN to the atmosphere to change precipitation patterns.

DISDROMETER – a ground-based instrument to measure precipitation properties.

GEOENGINEERING – deliberate, large-scale intervention in the Earth's climate system, usually to mitigate climate change.

ICE NUCLEI (IN) – similar to CCN, particles in the atmosphere that ice crystals form around.

PRECIPITATION – water that falls from clouds to the ground, such as rain, hail, snow or sleet.

SPECTROMETER – an instrument that measures spectral properties, such as the reflective properties of cloud particles.

WEATHER – the state of the atmosphere of a particular area at a particular time.

Rain, or the lack of it, can cause problems. Too little rain can lead to droughts, which carries risks of crop failure and scarcity of drinking water. Too much rain can cause flooding and other forms of precipitation, such as hail, can cause physical damage to crops and property. Being able to influence when, where and how much rain falls could help prevent these negative effects.

Darrel Baumgardner has made a career of investigating clouds, not only how they form but also how humans can influence their formation. As well as working within academia, he is the founder and Chief Scientist at Droplet Measurement Technologies, which provides scientific instruments and expertise to researchers investigating aspects of cloud formation.

WHAT IS CLOUD SEEDING?

A key step in the water cycle is when water vapour in the atmosphere condenses into clouds, but this process can only occur with the presence of cloud condensation nuclei (CCN). These are essentially small particles of any number of substances, such as dust, soot or salt. To transition from a gas to a liquid, water molecules have to have something to cling onto, and CCN fulfil this function. Ice nuclei (IN) are the CCN equivalent for the formation of ice crystals in the atmosphere.

DR DARREL BAUMGARDNER

National Autonomous University of Mexico and Chief Scientist at Droplet Measurement Technologies, Longmont, Colorado, USA

FIELD OF RESEARCH

Atmospheric Science

RESEARCH PROJECT

Investigating how clouds form, and how we can influence their formation.

Cloud seeding is a human-made technique that adds extra CCN or IN into the atmosphere, which can either enhance or suppress precipitation, depending on how, when and where it's done. This technique was famously used to keep the 2008 Beijing Olympics dry: rockets containing silver iodide particles (a type of IN) were fired into the atmosphere, intercepting incoming rainclouds and triggering premature showers before they could reach the capital.

HOW CAN YOU MEASURE SUCH A COMPLEX SYSTEM?

Atmospheric science is very complex, and scientists simply don't have all the information required to guarantee that cloud seeding will have the intended effect. In some instances, cloud seeding can even lead to the opposite effect to that intended. There is also a certain lack of control. "Once the seeding material is released, there is nothing more that can be done," says Darrel.

Measuring cloud properties, and how they react to different conditions, is essential. "There are two general types of instruments used to measure cloud properties," says Darrel. The first are called disdrometers, and measure precipitation at the ground, including variables such as drop size, velocity and type of precipitation. The second type measures the properties of clouds themselves and are called spectrometers. By fixing a spectrometer to an aircraft or drone and flying it through a cloud, scientists can record cloud water content and a number of other variables. Similar measurements can also be taken from a great distance, using radar or even satellites.

HOW CAN SCIENTISTS MODEL CLOUD PROPERTIES?

When it comes to modelling clouds to predict how they will respond to seeding, there are many factors to take into account, and at many different scales. For instance, the nucleation of cloud droplets around a CCN happens at the microscopic level and in a matter of milliseconds, whereas the time to grow to visible raindrops (and eventually entire clouds) can take minutes to hours. When this is expanded to include the interconnected cloud formation over entire regions, it gets complicated very fast.

However, this complexity is not insurmountable. "Modern computers have provided cloud modellers with the tools needed to create such models," says Darrel. Model inputs include temperature, pressure, relative humidity, CCN and IN specific to a certain time and area, and then different seeding scenarios are run to see how they affect cloud properties. As with any model, it remains a simplified representation of the real world, so results aren't perfect, but are getting more precise all the time.

THE BIGGER PICTURE

Cloud seeding could help mitigate against droughts, floods and even air pollution, but there are, perhaps, even bigger and more long-term applications. Geoengineering is the name given to techniques that aim not just to alter the weather but also the climate, to attempt to counteract the effects of climate change. When carried out at a global scale, cloud seeding and similar techniques are the most significant of these proposed measures.

"Geoengineering has the potential to offset the negative impacts of climate change," says Darrel. For instance, one effect of climate change is the absorption of the sun's heat by the oceans, which raises marine temperatures and can lead to ocean acidification – bad news for coral reefs and other underwater ecosystems. One project is looking into seeding stratus clouds over the Great Barrier Reef, which would deflect sunlight away from the sea's surface and mitigate warming in that area. In theory, this practice could be carried out worldwide.

However, given the complex nature of atmospheric science, geoengineering efforts on a global scale pose many challenges for scientists. For example, stimulating rainfall to alleviate drought in one area could lead to extreme monsoons in another. Experts in this field are mindful that they need to consider the intricacies of the bigger picture. As Darrel explains, with processes such as cloud seeding, there is always the, "Goldilocks conundrum" and the challenge is in getting things 'just right'. He adds, "As atmospheric scientists, we know that climate change is real." Scientists like Darrel can make a huge difference to our world – will you be one of them?

ABOUT ATMOSPHERIC SCIENCE

WHAT IS ATMOSPHERIC SCIENCE?

Atmospheric science studies the layers of gas that surround the planet, specifically their chemistry and their dynamics. This includes interactions within the atmosphere, and between the atmosphere and other entities, such as the ocean or human activity.

Our atmosphere is the relatively thin barrier that separates the Earth's surface from space. "Although the atmosphere makes up a small fraction of the Earth's volume, it is critical to life, not only for the oxygen we need but also for the hydrological cycle." The science that attempts to explain it is complex and detailed, but has come on in leaps and bounds in recent decades.

HOW HAS THE FIELD CHANGED OVER THE YEARS?

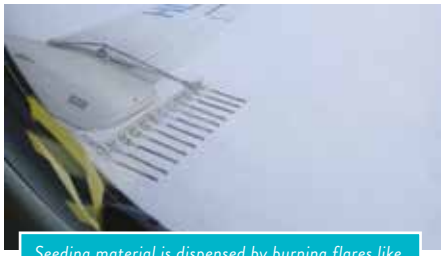
"We are now able to make faster and more accurate measurements with much smaller instruments," says Darrel. "We can also run computers hundreds of times more powerful than just a few decades ago." These huge advancements mean that understanding of atmospheric science is accelerating. "We know so much more about how clouds evolve than we did 50 years ago, but we still have a long way to go before we can truly 'control' weather," says Darrel.

WHAT ARE THE REAL-WORLD APPLICATIONS OF ATMOSPHERIC SCIENCE?

Weather forecasting, although it might seem a rather bland aspect of everyday life, has the potential to save countless lives. Forecasting tropical storms, tornados or hurricanes, for instance, can help people prepare and safeguard themselves and their livelihoods.

Atmospheric science also underpins much of what we know about climate change. "We know that climate change is real and is the greatest danger that the world faces today," says Darrel. Not only does atmospheric science provide us with much of the data about climate change – its predicted evolution and effects –, it also suggests ways we could protect ourselves against it.

Atmospheric science has a huge amount to teach us about the present and the future of our planet, and a career in it could have far-reaching positive impacts for society.



Seeding material is dispensed by burning flares like those seen attached to the trailing edge of the wing of this seeding aircraft.

HOW TO BECOME AN ATMOSPHERIC SCIENTIST

- According to NASA, a career in atmospheric science could begin with an undergraduate degree in meteorology, physics, chemistry, geography, mathematics, engineering or computer science.
- The Royal Meteorological Society has a list of UK universities that offer qualifications related to atmospheric science: https://www.rmets.org/courses
- According to College Factual, the top three universities in the USA for studying atmospheric science and meteorology are: Texas A&M University – College Station; University of California – Los Angeles; and University of Oklahoma Norman Campus
- Darrel highlights the University of Washington, the University of Wyoming, the Massachusetts Institute of Technology (MIT), Colorado State University and North Carolina State University as establishments to consider.
- According to Career Explorer, the average salary for an atmospheric scientist in the USA is about $94k.

HOW DID DR DARREL BAUMGARDNER BECOME AN ATMOSPHERIC SCIENTIST?

WHAT WERE YOUR INTERESTS AS A CHILD?

I was always curious as a child. I had my own chemistry set, Meccano, and lots of other educational toys that were available at that time. I enjoyed exploding things, taking things apart and putting them back together again. For a time, I was interested in becoming a writer, but decided to become a physicist at high school.

DID YOUR TEACHERS INFLUENCE YOUR DECISIONS?

I was lucky to have several inspirational teachers. My math teachers and my senior year physics teacher energised me with their enthusiasm for their subjects. A skilled teacher is driven by their curiosity and is someone who students want to emulate.

WHAT ARE YOU MOST PROUD OF FROM YOUR CAREER?

I have been a university professor for fourteen years and a research scientist for forty. I also have a patented design: the Backscatter Cloudprobe with Polarisation Detection. I have won an award for being the most cited Latin American scientist, with over 200 high-impact publications. I also founded my own tech company that does atmospheric research, which is still going strong after thirty years!

HOW DO YOUR ROLES IN ACADEMIA AND INDUSTRY COMPLEMENT EACH OTHER?

Many of my company's clients are academics, and I interact with them and their students. I often visit universities and give classes in cloud and aerosol physics, as well as teaching measurement and data analysis techniques.

WHAT'S NEXT?

I have too many goals to name! I hope to improve techniques for measuring cloud ice crystal properties, and to develop a better method for identifying pollen particles in real time.

DARREL'S TOP TIPS FOR STUDENTS

01 – Follow your instincts, and don't doubt yourself. Once you have made a decision, don't look backwards or regret your choice.

02 – Attributes such as curiosity, problem solving, creativity and exploring my own wild ideas have hugely helped my scientific career.

03 – Let your creativity grow and don't limit yourself. Being able to write well is essential, so read widely: history, literature, fiction, non-fiction. Music can also provide a great creative outlet.

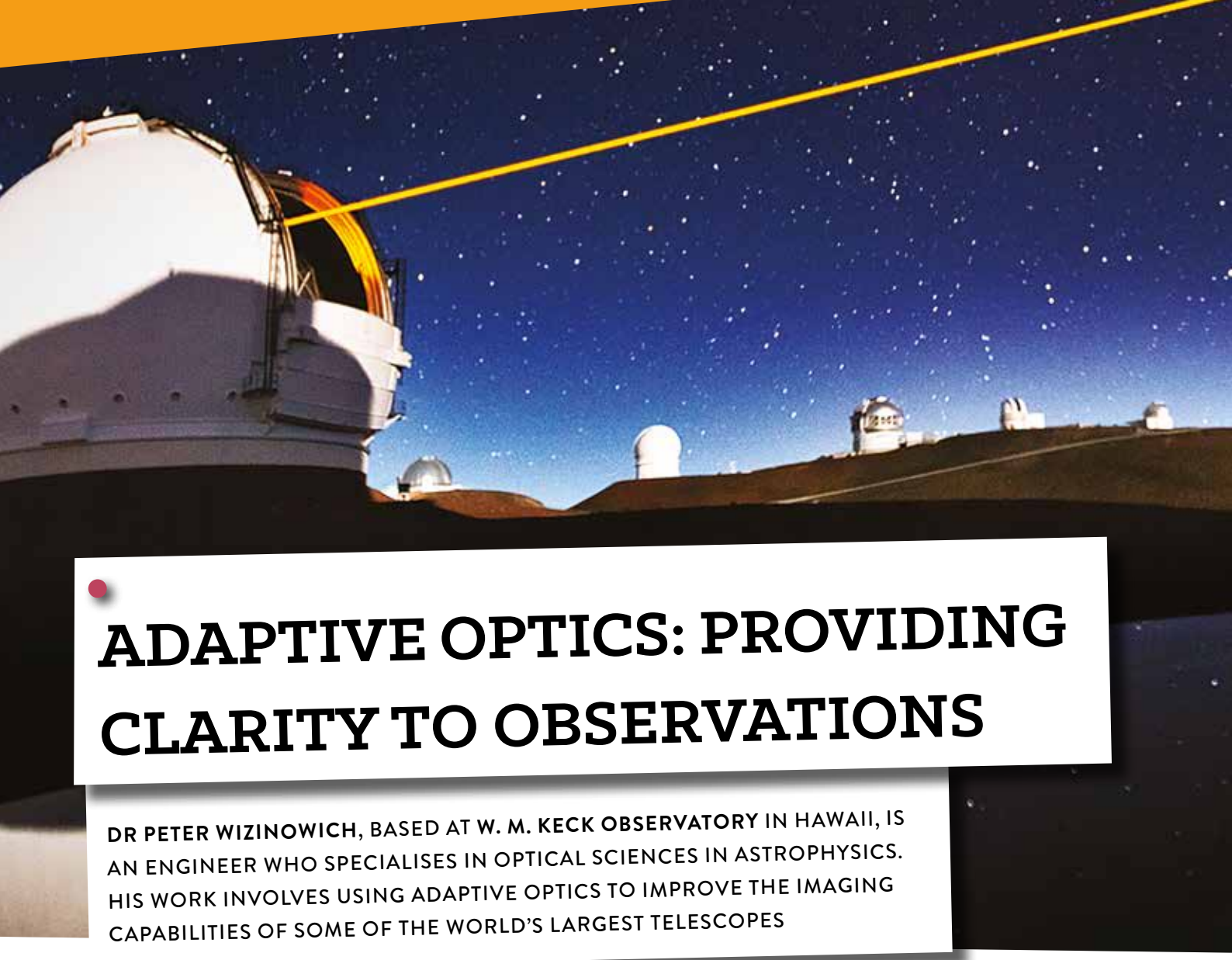
PATHWAY FROM SCHOOL TO ATMOSPHERIC SCIENCE

Darrel recommends taking:

MATHS → CHEMISTRY → PHYSICS

ENVIRONMENTAL SCIENCES

Other subjects such as geography and computer science could also be very useful.



ADAPTIVE OPTICS: PROVIDING CLARITY TO OBSERVATIONS

DR PETER WIZINOWICH, BASED AT **W. M. KECK OBSERVATORY** IN HAWAII, IS AN ENGINEER WHO SPECIALISES IN OPTICAL SCIENCES IN ASTROPHYSICS. HIS WORK INVOLVES USING ADAPTIVE OPTICS TO IMPROVE THE IMAGING CAPABILITIES OF SOME OF THE WORLD'S LARGEST TELESCOPES

In 1608, Dutch eyeglass maker Hans Lippershey patented the world's first telescope (although there is some debate concerning whether he stole the idea). Lippershey claimed his device could magnify an image up to three times. While that is hardly a bold claim from today's vantage point, it was the first important step towards building the many telescopes that now grace the world; after hearing about Lippershey's invention, Galileo designed his own telescope which magnified images up to 20 times, and the field of astronomy was born.

In the 400 years since then, telescopes have become significantly larger. The twin optical and infrared telescopes at the W. M. Keck Observatory in Hawaii, sit near the top of the dormant volcano, Maunakea, at an elevation of 13,600 feet. Both telescopes have a diameter of 10 metres, enabling researchers to observe the universe to a previously unimaginable degree.

However, while there is a general rule that the larger the telescope, the more detail it should be able to provide, turbulence in the Earth's atmosphere blurs astronomical images. Fortunately, scientists have found a way to overcome this issue.

HOW HAVE SCIENTISTS OVERCOME THE BLURRING EFFECT OF TURBULENCE?

Adaptive optics (AO). This is where deformable mirrors correct the distortion caused by atmospheric turbulence so the telescopes can view the skies in much finer detail. Dr Peter Wizinowich, Chief of Technical Development at Keck Observatory, is an engineer who specialises in optical systems in astrophysics. His work focuses on enabling astrophysics through AO, chiefly by adding new capabilities to one of the world's largest telescopes – the 10-metre Keck I and Keck II telescopes.

WHAT HAS ENABLED THE DEVELOPMENT OF OPTICS?

The concept of AO was proposed in 1951 by an astronomer named Horace Babcock. However, it is only in the last few decades that technology has developed to an extent where Babcock's proposal could be realised. Initially, the technology was limited to using bright stars that were relatively close to Earth to measure the distortions introduced by the atmosphere, but in more recent times, lasers have enabled astronomers to observe a much larger part of the sky.

"The key adaptive optics technologies include low noise, fast readout detectors to measure the light, fast computers to determine the corrections, and deformable mirrors to make the corrections," explains Peter. "The key laser technology was to develop a sufficiently bright laser, tuned to the wavelength of sodium to excite the sodium atoms in the Earth's mesosphere at an altitude of ~ 90 km to create the artificial star. In addition, instruments have been designed to make use of the AO-corrected light, including the development of large format, infrared detectors."

In 1999, Keck Observatory became the first in the world to implement both natural and laser guide star AO systems on a large telescope. Thus far, these systems have been used to

DR PETER WIZINOWICH

W. M. Keck Observatory, California Association for Research in Astronomy, Hawaii, USA

FIELD OF RESEARCH

Optical Science in Astrophysics

RESEARCH

Peter's work focuses on using adaptive optics to improve the capabilities of some of the world's largest telescopes.

Photo Credit: Andrew Richard Hara

provide data for more than 1,000 refereed science papers. Peter has led the efforts to improve and upgrade the systems over the past two decades.

WHAT RESULTS HAVE BEEN MADE POSSIBLE BY AO?

"A wide range of solar system, galactic, and extra-galactic science has been facilitated by the angular resolution provided by powerful AO systems on a 10-metre telescope," says Peter. "Prior to AO, the angular resolution of ground-based telescopes was 0.5 arcseconds. Keck AO has improved that resolution by a factor of 10 and the sensitivity to a faint star by a factor of 100."

These improvements have led to many notable results, such as determining there is a supermassive black hole near the centre of our galaxy with a mass of 4 million suns! The capabilities of Keck Observatory's telescopes have led to the creation of the University of California, Los Angeles (UCLA) Galactic Center Group. Under the leadership of 2020 Nobel Prize in Physics winner Andrea Ghez, the Group investigates the innermost regions of the Milky Way and the supermassive black hole at its centre, using the highest angular resolution possible.

Interestingly, Keck Observatory's AO observations also helped astronomers realise Pluto is not a planet, but rather, a dwarf planet.

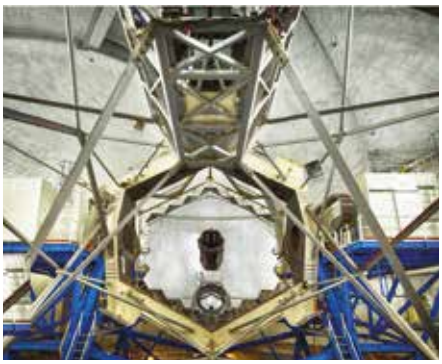
"Pluto is located in the Kuiper Belt. Keck AO measurements revealed the masses of some other Kuiper Belt objects that had moons and were similar in size to Pluto. This led to the discovery of a new class of objects, now called dwarf planets," explains Peter.

WHERE WILL AO AND RELATED RESEARCH LEAD TO IN THE FUTURE?

One of the most important reasons for putting telescopes in space is they are not subject to the atmospheric turbulence that AO seeks to correct. However, telescopes on Earth are far less expensive and easier to maintain – they can be larger, quicker to build, longer lasting, and easier to upgrade.

"Where Keck AO currently works well, at near-infrared wavelengths, it outperforms the much smaller Hubble Space Telescope (10 metres versus 2.4 metres)," says Peter. "However, we can't yet compete with the exquisite image quality of Hubble at visible wavelengths. One of our ultimate goals is to conceptually have the 10-metre Keck telescopes in space (without actually launching them) by having excellent AO-correction at visible wavelengths."

Maunakea hosts some of the most scientifically productive telescopes in the world, making Hawaii an international leader in astronomy. Most of the Maunakea Observatories have optical and infrared telescopes, but there are also submillimetre telescopes and a radio telescope.



The 10-metre diameter Keck Observatory telescope primary mirror consists of 36 hexagonal segments that are actively controlled with nanometer precision to work in concert as a single piece of reflective glass.

The Keck I and Keck II telescopes using their laser guide stars to observe the supermassive black hole at the centre of the Milky Way galaxy. The lasers excite sodium atoms in the Earth's mesosphere to create an artificial star that can be used to measure atmospheric turbulence.

ABOUT OPTICAL SCIENCE AND ASTROPHYSICS

In 1835, the French philosopher Auguste Comte said the chemical composition of stars could be an example of knowledge that might forever be hidden from humankind. However, unbeknownst to him, the development of spectroscopy (the study of the absorption and emission of light and other radiation by matter), was already leading to some exciting discoveries.

In the two centuries since then, we have come an incredibly long way. Humankind has been on the Moon, rovers have landed on Mars, telescopes have been put into space, and observatories around the world are discovering aspects of the universe that would have defied belief even just a few decades ago. Many of these observations have been made possible by the work of scientists like Peter, whose work on adaptive optics has enabled new astrophysics.

WHAT DOES PETER FIND MOST CHALLENGING ABOUT HIS WORK?

Peter has been at Keck Observatory for almost 30 years and in that time has overcome many technical and project management challenges. "One of the biggest challenges for someone like myself who wants to see new science capabilities come to life is finding the funding. So I spend time working with our science community to identify the future needs and our technical team to figure out how we are going to meet those needs, and then making proposals to both public and private organisations to fund these projects," explains Peter. "We have been quite fortunate to have groups support us like the W. M. Keck Foundation, the Gordon and Betty Moore Foundation, the Heising-Simons Foundation, the National Science Foundation, NASA, and others. Without their support we wouldn't be able to make our dreams come true."

HOW DOES IT FEEL TO HELP CAPTURE IMAGES OF THE UNIVERSE THAT NO ONE ELSE EVER HAS?

Peter says he feels very lucky to be part of the journey of discovery and to help enable those discoveries. Not an astrophysicist himself, it is his engineering expertise that has enabled plenty of talented and creative people to answer many of the big science questions. Without the efforts of people like Peter, it simply would not be possible to observe our universe in the detail that we currently can.

THE KECK ALL-SKY PRECISION ADAPTIVE OPTICS (KAPA) PROJECT AIMS TO INCLUDE MORE WOMEN AND UNDERREPRESENTED MINORITIES IN THIS FIELD. HOW SUCCESSFUL HAS THIS BEEN?

"We are already blessed in the Keck community and the KAPA project leadership to have a lot of female astronomers and students. Our project scientist, two of the four KAPA key science project leads, and our education lead are women. We would like our community and team to include more underrepresented people," says Peter. "More specifically, we would like to attract more women, local Hawaii residents, and minorities into instrumentation and engineering, and retain them in our community."

To achieve this goal, the AstroTech Summer School has been established. Unfortunately, the COVID-19 crisis has led to the cancellation of the first full event planned for 2020, but the team is looking at other ways to bring students together to support their future. The summer school aims to introduce late undergraduate and early graduate students to the process of designing and building a science instrument by providing extensive hands-on experience.

The KAPA project also hosts college students from Hawaii through the Akamai Internship Program.

HOW TO BECOME AN OPTICAL SCIENTIST:

- The Optical Society, of which Peter is a member, provides some useful information about the application of optics, as well as giving some interesting historical facts: **https://www.osa.org/en-us**, **https://www.osa.org/en-us/history**
- Peter is also a member of the engineering-orientated SPIE (The International Society for Optics and Photonics): **https://spie.org/education/education-outreach-resources**
- Study.com provides detailed information about the skills and qualifications required: **https://study.com/articles/optical_engineer_salary_job_description.html**
- Degrees in optical science, optical engineering, optics, or physics will help you in this field. Study.com provides detailed information about different degrees: **https://study.com/articles/Optical_Sciences_Degree_and_Course_Information.html**
- According to Study.com, the median annual salary for an optical engineer is $89,540.

PATHWAY FROM SCHOOL TO OPTICAL SCIENCE

Peter says a good basis in mathematics and physics will serve budding engineers and astrophysicists well, and the opportunity to do research projects and gain confidence and experience is important. "I play an engineering and project leadership role at Keck Observatory. The observatory's technical staff includes electronics, mechanical, optical and software engineers, technicians, and astronomers," says Peter. "I find it very useful to maintain an overall system perspective, while bringing my own expertise to projects. Having some understanding of each of these disciplines is useful for communication and to know where a problem can be best addressed."

HOW DID DR PETER WIZINOWICH BECOME AN OPTICAL SCIENTIST?

DID YOU ALWAYS WANT TO BE A SCIENTIST?

Astronomy interested me from a young age. I was especially intrigued by how much astronomers could learn just from light. They seemed to be the most clever and inventive detectives to me! Science fiction also played a role in my interests beyond our planet. I studied physics and astronomy in college and eventually found myself more interested in – and my talents more suited to – building the astronomical instruments as opposed to doing the astronomy myself. This led to my pursuit of a PhD in optical sciences after working in astronomical observatories for several years.

WHO OR WHAT HAS INSPIRED YOU IN YOUR CAREER?

The mysteries of the universe are pretty inspiring and being able to play a role in understanding those mysteries is always inspirational – I love being part of an observatory. I have enjoyed working at a research level at universities, but I prefer turning research concepts into working science capabilities. I have managed to work with some very talented people who have challenged me, taught me, and helped me up my game throughout my career.

WHAT ARE SOME OF THE DAY-TO-DAY OBSTACLES YOU FACE IN YOUR WORK AND HOW DO YOU OVERCOME THEM?

What I really enjoy doing is developing an initial concept then taking it through all the steps and challenges to something that is working operationally every night to enable new science. There are day-to-day challenges involving project management, technical issues, and distractions from other aspects of my role. However, knowing these are just part of the process helps overcome the little day-to-day obstacles. There have been many larger challenges over the years, but experience tells me these will be behind us one day and we will find a way to get our work done.

WHAT ARE YOUR PROUDEST CAREER ACHIEVEMENTS?

At Keck Observatory, some of my proudest achievements have included the telescopes, the adaptive optics systems, and the interferometer that combined the light from the twin Keck telescopes. I have had an opportunity to play a leading role in each of these. I'm also pleased to have played a role in the development of engineers and postdocs at Keck Observatory, and to have developed collaborations with AO groups and people around the world. It is a great community to be a part of. I am proud of starting the AO programme at Steward Observatory (prior to my time at Keck Observatory), my PhD research, and early career roles at the Canada-France-Hawaii Telescope and the University of Toronto telescope in Chile.

HOW DO YOU 'SWITCH OFF' FROM THE COMPLEXITIES OF YOUR WORK?

I'm not sure I switch off enough! However, I do enjoy swimming, hiking, biking, reading, travelling, and spending time with my family.

Photo Credit: Andrew Richard Hara

HOW TO BECOME AN ASTROPHYSICIST:

- The American Astronomical Society is a robust resource for those interested in understanding the universe. There is a section dedicated to career information and advice, including internships and summer jobs: **https://aas.org**
- The National Space Society is another brilliant resource. There are even contests and competitions you can participate in: **https://space.nss.org**
- You'll usually need a degree and postdoctoral experience to work as an astronomer. Relevant subjects include math, physics, astrophysics, geophysics, astronomy, and space science: **https://nationalcareers.service.gov.uk/job-profiles/astronomer**
- Study.com also has useful guidance on astronomy and has the median annual salary at $105,680: **https://study.com/articles/Astronomer_Job_Information_and_Requirements_for_Students_Considering_a_Career_in_Astronomy.html**

PETER'S TOP TIPS FOR STUDENTS

1. Find an area of scientific interest that you enjoy and where you want to make a contribution. Knowing that you're doing something worthwhile will help you get through challenging times.
2. Never be afraid to explore ideas and take opportunities to challenge yourself. When you find you are up to the challenge, this will increase your confidence and allow you to move on to bigger challenges.
3. Keep in mind you will struggle at times and make mistakes – these are opportunities to learn and grow. It helps to have your eye on longer-term goals as you address the obstacles that will lie along the path toward those goals.

AIMING FOR THE STARS

THERE IS STILL A HUGE AMOUNT WE DO NOT KNOW ABOUT THE GALAXY WE INHABIT. THE MAJORITY OF THE MILKY WAY REMAINS UNMAPPED AND MYSTERIOUS. **PROFESSOR TOM BANIA** OF **BOSTON UNIVERSITY** IS CHIPPING AWAY AT THESE UNKNOWNS, USING THE LATEST TELESCOPE TECHNOLOGY TO REVEAL EXACTLY WHAT IS FAR BEYOND OUR PLANET'S NEIGHBOURHOOD

TALK LIKE AN ASTRONOMER

CELESTIAL BODY
Any natural astronomical object, such as stars, planets and asteroids.

GALAXY
A system comprising stars, gas and dust, held together by gravity.

IONISED
Atoms or molecules that carry an electrical charge.

KINEMATIC DISTANCE
Working out distances between celestial bodies by calculating their relative velocities.

NEBULA
A cloud of dust or gas in space.

RADIATION
Emission of energy as electromagnetic waves. The electromagnetic spectrum includes radio waves, microwaves, infrared, visible light, ultraviolet, X-ray and gamma rays.

SUPERNOVA
A star that is undergoing an explosion, resulting in the scattering of its mass and a sudden increase in brightness.

With every passing year, leaps forward in technology, scientific equipment, computing power and innovative thinking have paved the way for ever-greater discoveries in astronomy. Professor Tom Bania, of Boston University's Department of Astronomy, is using the latest telescopes and galactic mapping expertise to uncover the locations of nebulae within the Milky Way.

HII REGIONS: BUBBLES OF SPACE GAS

The most massive stars in our galaxy, known as OB stars, are 20-50 times the mass of our Sun. They emit a huge amount of ultraviolet radiation over the course of their (comparatively short) lifetimes, which cause hot bubbles of ionised gas to form. These gas bubbles, a type of nebula, are known as HII regions, and are where Tom's research currently focuses.

An OB star has an immensely powerful nuclear reactor at its core, which fuses together atomically light elements (such as hydrogen and helium) into heavier elements. When it reaches the end of its life, a massive OB star becomes a supernova – in other words, explodes – and disperses these elements into space. Eventually, they may coalesce into planets and other celestial bodies. The existence of life depends on supernovae. "Every iron atom in our blood, for example, was formed deep inside an OB star," says Tom.

NEW NEBULAE

Tom's research team works on discovering previously unknown HII regions in our galaxy. "These new nebulae are extremely far away from the Sun," he says. "Previous generations of telescopes couldn't detect the signals they gave off. We also just didn't know where to look – space is a big place, after all."

Different telescopes detect electromagnetic radiation of different wavelengths. With visible light, for instance – the same wavelengths we use for vision – we can only see about one-third of the distance to the centre of the Galaxy. We can use infra-red and microwaves to see further, and radio waves to see the furthest of all - anywhere within the Galaxy, in fact. "The dust in the Galaxy absorbs electromagnetic radiation. Visible light is the most absorbed and radio light the least. This means that the extremely bright radio emission from HII regions makes it possible to find these nebulae even if they are at vast distances from Earth," Tom explains. "Through discovering over a thousand distant HII regions, we can now drastically improve our map of the Milky Way."

A BIG TELESCOPE FOR A BIG JOB

"Modern telescopes mostly benefit from advances in electronics and computer power, and have come on a long way since I began observing HII regions in the 1970s," says Tom. The Green Bank Telescope (GBT), which was

TOM'S TOP TIPS FOR STUDENTS

1. To quote the mythologist Joseph Campbell, "Follow your bliss." I am a working-class kid, and I followed my bliss. Remember, as an undergraduate, you are the customer – you pay them for your education. As a graduate you become an employee, and effectively get paid to be a student. That's sweet!
2. Learn electronics and programming. These skills will help you get a job anywhere, not just in astronomy.
3. If you are not happy doing what you are doing, find something else that does make you happy. Life is too short.

PROFESSOR TOM BANIA

Astronomy Department Institute for Astrophysical research, Department of Astronomy Boston University, USA

FIELD OF RESEARCH

Astronomy

RESEARCH PROJECT

Detecting and mapping the presence of HII regions throughout the Milky Way.

Credit: NRAO/AUI/NSF The Green Bank Telescope is the world's largest, fully-steerable telescope. THE GBT's dish is 100-meters by 110-meters in size, covering 2.3 acres of space.

crucial for his research, also benefits from clever mechanical design. It essentially looks like a TV satellite dish but is a whopping 100 metres in diameter. "The GBT is unique because it can pick up frequencies spanning a very wide portion of the radio wave spectrum," says Tom.

HII regions are highly ionised, and the charged particles within them are steadily combining to form neutral atoms. This process gives off a signal: when an electron drops down from a very high energy level, it produces a photon at a specific frequency. The GBT can be 'tuned' to detect this frequency, and so detect the presence of HII regions.

BUILDING THE GALACTIC MAP

Even once these signals are picked up, it's difficult to tell how far away the HII regions are. "Determining the distances to celestial bodies is one of the hardest parts of astronomy," says Tom. One clever technique astronomers use is known as 'kinematic distance', which involves measuring how fast an object is moving relative to Earth. Tom explains, "The relative velocity of the HII region, with respect to the Earth, can be used to determine the distance to the nebula and this is known as a 'kinematic' distance. The word stems from a Greek root that means 'motion'." To measure this velocity, astronomers use the 'Doppler effect', where wave frequencies change due to the relative motion between the object and the measurer. It's the same effect that makes police sirens drop in pitch when the vehicle is moving away from you. Once they have determined this relative velocity, astronomers can derive the kinematic distances to HII regions using their knowledge of how the Galaxy rotates about its centre.

Tom's research team aims to produce 'the first complete map of where massive stars are forming in the entire Milky Way disc'. This is no small task. "We have just completed our Southern Hemisphere HII Region Discovery Survey," says Tom. "We found over 500 previously unknown HII regions, adding to a total of over 2,500 nebulae recorded in the Milky Way." Now, they are working to understand exactly how the Milky Way rotates, so that they can determine kinematic distances between HII regions and add these points to the galactic map.

HOW ANSWERS LEAD TO QUESTIONS

The project is also giving interesting insights into the wider galactic make-up. There are more stars (including more OB stars) near the centre of the Galaxy, which means that you would expect there to be more heavy elements there – which is exactly what they found. Nonetheless, at any given distance from the centre, you would also expect there to be about the same abundance of heavy metals in any direction. The researchers have instead found localised pockets of heavy element abundance, and are currently trying to work out why this is the case. "This result would not have been possible without a large sample of HII regions," says Tom.

The work of Tom and his team highlights just how much there is more to learn. The sum knowledge of astronomy is growing exponentially as more and more observations become possible, which means that exciting discoveries are happening every year. As with HII regions, each discovery also raises a raft of new questions, which will shed more light on what makes our universe tick.

ABOUT ASTRONOMY

THE ART OF DISCOVERY

Since there is still plenty that we don't know about the universe, much of astronomy is about discovery. "I have had my share of discoveries, and they are extremely satisfying – more than satisfying, actually," says Tom. "Nothing worthy of the Nobel Prize, but each time I celebrate with colleagues, with fine wine and gourmet food."

Of course, as with any science, there are sometimes setbacks too. "I have a couple of missed discoveries, and these haunt me. One was on a figure in one of my first papers, an effect that just looked like 'noise' (that didn't appear to be a real signal), but thirty years later was found to be a spiral arm of the Milky Way."

WHAT KEEPS ASTRONOMERS UP AT NIGHT

Like any field, astronomy has its fair share of challenges. "The practical challenges are the same as with any science," says Tom. "Accessing the latest instruments, getting funding, finding permanent jobs… Same old, same old."

Where astronomy becomes more unique is in the sheer scale of the undiscovered. "If our interpretations are valid, only about 4% of the universe is made up of atoms that we are familiar with," Tom continues. "The remainder is dark matter and dark energy, which we know very little about – and that's uncomfortable."

THE NEXT GENERATION

"There is great satisfaction in sharing mutual joy in the process of research with my students," says Tom. "I have learned that one cannot teach how to do research, only show by example. Half the time it doesn't take, but when it does, many go on to an astronomical research career. Then, I enjoy collaborating with them for many more years."

Boston University has weekly free open nights for the general public, where they are invited to look round the campus observatory. Green Bank Observatory also runs the 'Physics Inspiring the Next Generation' summer camps, where Tom often mentors or lectures. "These kids are awesome!" he says. "Excited, engaged – the whole deal."

HOW TO BECOME AN ASTRONOMER

- According to UK Uni, the top UK universities for physics and astronomy are the Universities of St Andrews, Cambridge, Oxford and Durham.
- According to Top Universities, the top USA universities for physics and astronomy are MIT, Harvard, Stanford and California, Berkeley.
- In the UK, there are 'Space Schools' for teenagers based in the Universities of Leicester, Kent and Glasgow.
- In the US, there are similar projects to the Green Bank Observatory's summer camp in several states. Arizona has the Astronomy Camp (astronomycamp.org) which offers 'immersive' STEM camps for teenagers, including real scientists as mentors.
- In the USA, salaries for astronomers tend to fall between $111,663 and $130,927, according to salary.com.

PATHWAY FROM SCHOOL TO ASTRONOMY

Tom recommends high school students take maths, physics, and astronomy if it's available. Chemistry also helps, and he advises learning computer programming.

MATHS

PHYSICS

ASTRONOMY

COMPUTER PROGRAMMING

CHEMISTRY

To become a fully-fledged astronomer, a degree and postgraduate qualification is usually required, and PhDs are common. Undergraduate subjects like astronomy, physics, maths, astrophysics, geophysics and space science can lead to a career as an astronomer.

HOW DID PROFESSOR TOM BANIA BECOME AN ASTRONOMER?

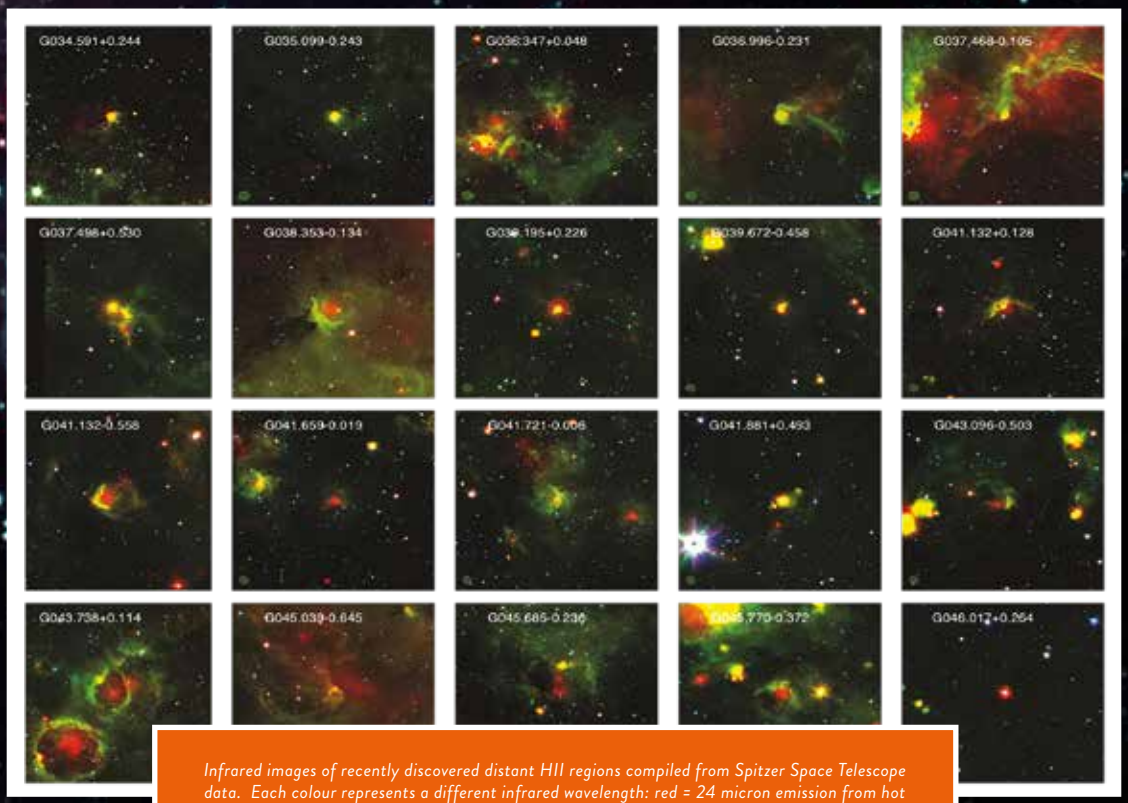
What were your interests as a child?
Sports of all types were a big interest, as well as reading anything I could get my hands on. I always knew that I wanted to be a scientist. I was helped greatly by Sputnik (the first satellite ever launched by humankind – launched by Russia), which kicked off the 'space race' between Russia and the USA. As a consequence, the USA funded a host of summer programmes for kids, intended to inspire the next generation of American scientists. It certainly worked for me!

What led you to choose astronomy?
I started university as a chemistry major. In my junior year at Brown University, I discovered that I could actually get paid to do astronomy. That's what sealed the deal. I have had great scientific mentors too, especially my PhD advisor.

What has helped you become a scientist?
Being smart and motivated, and being able to do things with my hands. I believe that the most important trait for a scientist is to have that 'fire in the belly'. I have seen many people much smarter than me fail as researchers, often because things had been too easy for them up to that point, and also because there is a big difference between following instructions and taking tests, compared to defining your own problems and tackling them through research.

How do you overcome obstacles in your research?
Stick with it. That's why it's called 'REsearch', after all. When really stuck, I find something else to do for a while, then try again. This can be years – I have examples where I tried to make observations that were technically impossible, but 25 years later, advances in scientific instruments have allowed me to make them.

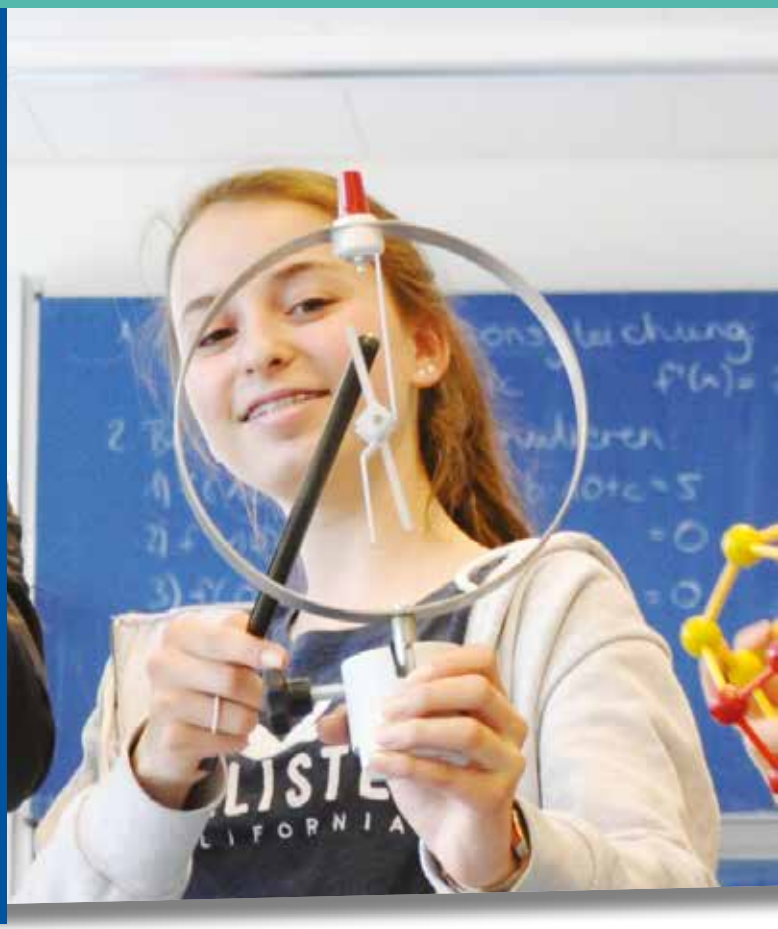
What career goals do you have left to achieve?
None really – I am 70!



Infrared images of recently discovered distant HII regions compiled from Spitzer Space Telescope data. Each colour represents a different infrared wavelength: red = 24 micron emission from hot dust inside the HII region, green = 11 micron emission from polycyclic aromatic hydrocarbon (PAH) molecules at the edge of the HII region, and blue = 4 micron emission from stars in the field. Each image is a square that is 5 arcmin on a side. The full Moon is 6 times bigger than each image!

CAN RESEARCH HELP IMPROVE STEM EDUCATION ACROSS EUROPE?

THE AIM OF **ICSE** (INTERNATIONAL CENTRE FOR STEM EDUCATION) IS TO HELP IMPROVE STEM EDUCATION ACROSS EUROPE THROUGH PRACTICE-RELATED RESEARCH AND ITS TRANSFER INTO PRACTICE. **PROF DR KATJA MAAS**, ICSE DIRECTOR, EXPLAINS WHY STEM EDUCATION RESEARCH IS SO FUNDAMENTAL



You are a professor at the Institut für Mathematische Bildung (IMBF). Is your background in maths?
I studied mathematics, biology and informatics to become a secondary teacher, which I did for 10 years. During this time, I started writing papers – and my thesis – about mathematics education. I was awarded professorship in 2004.

Who or what inspired you to study and follow a career in maths?
I have loved mathematics since I was a child. I had a fantastic mathematics teacher in primary school who inspired me. I was fascinated by numbers, solving problems and getting insight into a new world of mathematics.

Why are you passionate about STEM education?
As a passionate teacher, I want students to appreciate the relevance of STEM for our societies, to understand fundamental scientific principles, and be empowered to live as responsible citizens. I want to encourage students to take up careers in the STEM sector. Not only is there an urgent need for employees, but STEM is important to our societies and way of life.

HOW WOULD YOU DESCRIBE THE CURRENT STATE OF STEM EDUCATION ACROSS EUROPE?

As far as I can see, currently in most European countries, STEM education does not include enough real-life applications. I think STEM education should focus more on showing students what the applications are, alongside the relevance of STEM subjects to society.

Why should you learn about geometry, genetics, chemical elements and so forth if you cannot apply it to the world and use it as an active citizen? Notwithstanding, it is worth working on a problem from mathematical perspective. It provides you with problem-solving strategies and encourages creative thinking.

It is also important to show how STEM is connected with the world. The need for this approach has become particularly evident during the coronavirus crisis. People feel uncertain because they do not understand why statements from virologists keep changing over the course of time.

WHY IS RESEARCH SO FUNDAMENTAL TO IMPROVING STEM EDUCATION?

If you want to introduce a medicine into the market, nobody would question the necessity of research on whether it is curative or not. If you want to fly an aeroplane, there is hopefully research on whether or not it stays in the air as intended. Pupils are the future of our society; they need to be educated so that they have sufficient knowledge and competence to live their lives as active citizens. There needs to be rigorous research-based knowledge on whether certain teaching approaches are suitable to reach these aims.

As another example, when you educate prospective teachers or run professional development (PD) courses, research-based evidence is needed to find out whether teachers are able to implement certain teaching approaches after the course.

HOW DOES ICSE ENSURE THAT ITS RESEARCH PROJECTS ARE SUCCESSFULLY TRANSFERRED INTO THE CLASSROOM?

All our projects have the explicit intention of transferring research knowledge into the classroom. The idea is to develop classroom materials and PD courses that are based on STEM education research. Thus, the steps are: We read research on, for example, inquiry-based learning (IBL), applications in real-life, connections to the world of work (WoW), citizenship education, and so on, and based on this knowledge we develop

materials for day-to-day classroom teaching and PD courses. We then run the courses and carry out new research aimed at showing the impact of the materials on day-to-day teaching or the impact of our PD courses on teachers. We also develop detailed dissemination plans for each project, in order to ensure that the materials and course content become available to a broad mass of teachers and thereby find their way into classrooms all over Europe.

ICSE PUBLISHES QUARTERLY PROBLEMS. CAN YOU EXPLAIN THE AIM OF THESE PROBLEMS AND HOW TEACHERS MIGHT BE ABLE TO USE THEM?

We want to present teachers and students with current problems from the world around them that can be solved with STEM. Thereby, we help students comprehend the actual utility and applicability of STEM subjects, and connect STEM with topics that might affect their everyday lives, such as love, vacations, chocolate production, etc.

In order to give teachers and students continuous insight into such problems, we decided to produce them regularly and send them out to all of our subscribers. We now have three different quarterly problems: One for mathematics, one for science and one for ecological questions (the green edition). They are designed as students' worksheets, which can be used in class; they also give hints to students. Teachers who want to use them only need to reflect briefly on how to introduce the problem, then decide on the methods they want to use (i.e. having students work in groups on the problem, and so on) and then get started. They are easy to use and fun or/and relevant to nature!

ARE THERE ANY OTHER RESOURCES TEACHERS CAN ACCESS THROUGH ICSE?

Since the beginning of April 2020, ICSE publishes weekly "Mathematics and Coronavirus" tasks, which are, again, worksheets for direct use in class. They illuminate up-to-date coronavirus issues, and students work through them to gain insight into how the crisis can be mastered with the help of mathematics. Until recently, these tasks were only available in German, but they are now available in English on our website.

Moreover, ICSE develops materials for teaching through all its research projects (namely IBL, connections to real life, WoW, interdisciplinary STEM teaching, citizenship education and diversity). We produce classroom materials, materials for teacher education and for professional development. You can find these materials here:

https://www.fi.uu.nl/publicaties/subsets/masdiv_en/
https://www.fi.uu.nl/publicaties/subsets/icse_en/

FINALLY, WHAT IS YOUR HOPE FOR STEM EDUCATION IN THE NEAR AND FAR FUTURE?

My vision for STEM education is that it inspires young people into STEM subjects, supports them in doing IBL (instead of following strict algorithms), and shows them how to apply STEM subjects and how knowledge is gained in STEM subjects. Finally, I want STEM education to enable young people to act according to their values and become responsible citizens. I hope that, increasingly, curricula and assessment procedures across the world include these aspects, and that increasing numbers of teachers teach in this way.

ABOUT ICSE

ICSE is located at the University of Education in Freiburg, Germany, and focuses on practice-related research and its transfer into practice. It sustainably links stakeholders from research, practice, policy and industry, nationally as well as internationally, through the ICSE consortium.

The ultimate aim of ICSE is to help improve STEM education across Europe. That is, to give students insights into authentic features of STEM subjects and their connection to real-life contexts, to raise achievement levels in STEM subjects and to make science literacy accessible to all students, no matter their gender, their cultural or socioeconomic background. Thereby, ICSE intends to promote the interest of young people in STEM careers.

ICSE RESEARCH

Check out ICSE's website: https://icse.eu

ICSE and its partners focus on six areas: inquiry-based learning (IBL), connections to the world of work (WoW), real-life contexts, interdisciplinary STEM teaching, diversity in classrooms, and citizenship education. Here are two examples:

GEM – Empower Girls to Embrace their Digital and Entrepreneurial Potential

GEM's mission is to close the gender gap in Europe's labour market in the natural sciences and advance digitalisation. Aimed at girls, a number of summer camps around Europe will introduce girls to the complex but exciting facets of STEM and ICT in order to inspire them to study these subjects and eventually choose a career in the natural sciences.

Another aspect of this project addresses the girls' environment, namely (1) families/friends/close human environment, (2) business/industry representatives, (3) policy makers and media, and (4) educational stakeholders such as teachers, HEI, informal learning providers. The GEM network members, representatives of the named further target groups, will agree on purposeful measures in order to achieve lasting effects in supporting girls to choose STEM/ICT carriers.

https://icse.eu/international-projects/gem/

mascil – Inquiry-based learning and connections to the world of work

In this project, 18 partners from 13 countries collaborated to develop classroom and professional development (PD) materials that connect IBL in school with the WoW. The aim is to make science more meaningful for young European students and motivate their interest in careers in related fields.

With mascil, ICSE developed an international PD course to encourage and enable teachers to implement an innovative teaching approach to connecting IBL to the WoW in their day-to-day teaching. Their research came up with some interesting results:

- At the beginning of the PD course, the teachers who felt more supported by the school context (curriculum, assessment, curriculum materials) had more connections to the WoW than others. For example, if they felt the curriculum related to IBL and the WoW, or that they had access to relevant classroom resources, they were more likely to include IBL and WoW in their teaching.

- Teachers' views on the WoW, classroom management, time and, in particular, policy support (e.g. the curriculum, assessments, political goals) influenced teaching practice.

- Teachers who felt they were supported by policy felt less pressured by time issues. This emphasises the important role policy has on implementing innovations in day-to-day teaching.

- The ICSE study found a correlation between classroom management and time. Teachers who had difficulties managing their classes seemingly needed more time for classroom management and therefore felt pressured by time issues. This indicates that PD courses, aimed at implementing connections to the WoW or IBL, should also include aspects of classroom management.

- After the PD course, teaching practices changed with teachers using more connections to the WoW.

- There were also significant changes in teachers' attitudes to classroom management, policy support and the WoW after the PD course. Teachers felt they had fewer problems with classroom management and that they were more supported by policy. The PD course pointed to connections between the curriculum and policy documents, helping teachers to change their perspectives on policy support.

https://mascil-project.ph-freiburg.de

"I woke up from a nightmare and decided to study neuroscience that morning."

BEN REIN, A NEUROSCIENCE PHD CANDIDATE AT SUNY BUFFALO JACOBS SCHOOL OF MEDICINE & BIOMEDICAL SCIENCES, EXPLAINS WHY HE HAS SET UP A FREE NETWORKING PLATFORM FOR STUDENTS, CALLED **ASPIRING SCIENTISTS COALITION**, AND HOW TALKING TO PROFESSORS HELPED HIM ON HIS JOURNEY TO BECOMING A NEUROSCIENTIST

Science is an incredible field, and there's no doubt about it – a successful career in science can be tremendously exciting and rewarding. I can't imagine a more satisfying way to spend my life, than studying the brain and its diseases, working to uncover information that may improve the welfare of others. The only problem is, science can be a bit confusing. As I've made my way through my bachelors & PhD degrees, I've found that students in science seem to face many more difficult questions and major decisions than those in other fields. Choosing the right major, finding research experience opportunities, figuring out which graduate programmes are right for you, understanding the available career options – it can be a real whirlwind, and very few students get everything right the first time. But in my experience, the students who consult the resources around them (professors, clubs, etc.) and actively seek guidance as they face these challenges are the ones that do the best.

As an undergraduate student, I was majoring in psychology until I literally woke up one morning and decided to study neuroscience. The truth is, I awoke from an unbelievably vivid nightmare, and was totally amazed that my brain was powerful enough to generate such an incredible experience. I had three semesters until graduation, and had to find my way. I joined clubs, volunteered in research labs, and sat down with as many of my professors as I could. I found that I walked away from every single conversation with a few more valuable pieces of information. I'm now in the 5th year of my PhD in neuroscience, a few months away from graduation, and I am incredibly grateful for the mentors and colleagues who have helped shape my trajectory. I've learned firsthand that in order to answer the many questions that science poses, you have to speak with those who have stood in your shoes, and progressed to the next step.

In order to address this issue and provide this same guidance and advice to the next generation of scientists, I've created a free, online organisation called the Aspiring Scientists Coalition (ASC)! ASC is designed to connect students interested in science with professionals in the field, to enable them to ask questions, build their scientific network, and gain valuable guidance and mentorship. It's totally free to join, and all are welcome. Currently, our group has nearly 300 members from 17 countries worldwide! By becoming a member of ASC, students gain access to online meetings that rotate between Q&As, networking sessions, and scientific presentations to help members identify their passions and interests. Especially in the age of COVID, where it is even more difficult to form these connections and have these conversations, we want to make information accessible. We hope to unite the next generation of scientists, and shape science into a more collaborative field. To sign up, please visit our site: ASCscience.com – and if you have questions or would like to get involved in an administrative role, please feel free to contact me directly!

A VIRUS THAT CAN ACTUALLY SAVE US FROM HARM!

DR KARYNA ROSARIO IS BASED WITHIN THE MARINE GENOMICS LABORATORY AT THE **UNIVERSITY OF SOUTH FLORIDA** IN THE US. HER RESEARCH, FOCUSING ON VIRAL METAGENOMICS, HAS LED TO THE DISCOVERY OF A NOVEL INDICATOR THAT HELPS DETECT HARMFUL PATHOGENS IN WASTEWATER. THE FINDINGS WILL LEAD TO SAFER LIVES FOR ALL OF US

Human enteric pathogens are microbes that affect the intestine and can make people unwell. Most of us will have heard of *E. coli* and salmonella, which are enteric pathogens often found on food products that have not been prepared adequately, but there are many more that can cause sickness, diarrhoea and even death. For that reason, human enteric pathogens are of interest to scientists, both in terms of identifying their presence and finding means of combatting them.

Dr Karyna Rosario is a marine scientist who has worked on just that. She is based within the Marine Genomics Laboratory at the University of South Florida in the US and her research has contributed to the development of strategies for effective microbial water quality monitoring and the assessment of wastewater treatment technologies. When we flush the toilet, many of us don't give a second thought to what happens to the water, but there are many pathogens in human excreta that can become present in domestic wastewater. This is potentially problematic, as domestic wastewater is ultimately released back into the environment and, if this water contains human pathogens, it could make people sick after coming into contact with it.

WHAT METHODS ARE USED TO DETERMINE THE PRESENCE OF PATHOGENS IN WASTEWATER?

E. coli is an example of faecal indicator bacteria (FIB). The presence of FIB in a sample of wastewater suggests the presence of pathogens that have originated from faecal matter. "Historically, FIB have been used to determine the microbial quality of water samples worldwide because they are affordable and easy to test," explains Karyna. "Unfortunately, FIB detection (or lack thereof) does not necessarily tell us anything about the presence of actual human pathogens and/or health risks associated with a given water resource. This is particularly true for viruses, which are entirely different from bacteria." For these reasons, it is important that better indicators are developed, especially for waterborne viruses.

HOW IS KARYNA WORKING TO DEVELOP BETTER INDICATORS?

One of the most interesting outcomes of Karyna's research is the use of a virus to help identify the presence of human enteric pathogens. Her team noticed that the pepper mild mottle virus (known as PMMoV and present in common food items such as chili sauce) was abundant in wastewater and present in most of the samples that contained human pathogens of concern – this essentially means that if PMMoV is present at certain levels in a given sample, it is an indicator that there might be a risk of becoming sick if precautions are not taken.

WHAT ARE THE ADVANTAGES OF USING PMMOV AS A SURROGATE VIRAL INDICATOR?

Karyna's mentor and PhD advisor, Dr Mya Breitbart, had done some previous work that showed PMMoV is really abundant in excreta from healthy individuals. Then, when Karyna looked at viruses in reclaimed water (the reusable end product of wastewater treatment) for her PhD project, she found PMMoV makes it through the treatment. "We wondered if PMMoV could be used as a viral indicator of human faecal pollution and started looking at PMMoV in wastewater and environmental samples," explains Karyna. "PMMoV is a plant-

DR KARYNA ROSARIO

College of Marine Science
University of South Florida
USA

FIELD OF RESEARCH

Marine Science

RESEARCH

Karyna's work identified the pepper mild mottle virus as an indicator of domestic wastewater pollution. The findings will lead to improvements in wastewater treatment and help humans lead healthier and safer lives.

FUNDER

National Science Foundation

infecting virus rather than a human virus and, similar to FIB, it is not a health threat when working in the lab."

In addition, because PMMoV is dietary in origin, its concentration in wastewater does not depend on active infection of the population. "This is ideal because it is not practical to test for all enteric pathogens which may exhibit different dynamics and seasonality. For example, if we are testing for norovirus specifically, but there is a different viral infection in the population, we would completely miss that there are other pathogens in our samples," says Karyna. "PMMoV is found in high concentrations in wastewater, compared to other viral indicators or pathogens, and can be readily detected regardless of season."

HOW WILL THESE FINDINGS BE USED IN THE FUTURE?

Karyna is the first to admit that not everyone likes to talk about viruses, especially related to reclaimed water, and, initially, some community stakeholders were reticent to listen to her findings. Resilient and passionate about scientific endeavour, Karyna persisted in talking to people about her work. She was supported by her colleague, Dr Erin Symonds, who worked hard to encourage other researchers to incorporate PMMoV into their studies, and, of course, her mentor, Mya. The team is now hopeful that PMMoV will become part of the methods used to safeguard public health.

However, more work needs to be done on developing methods that are easier, faster and cheaper. "One of the limitations we face when detecting PMMoV is that we rely on molecular methods that are time-consuming and require highly trained or specialised individuals and equipment," says Karyna. "The good news is that PMMoV has been studied for a long time given that it is a plant virus that has threatened the agricultural sector for decades." Ultimately, this puts Karyna and the team at an advantage – techniques for PMMoV detection already exist, albeit in the agricultural sector. The plan is to take the learnings from there and adopt them for water quality purposes, which will benefit everyone and safeguard them against harmful viruses.

ABOUT MARINE SCIENCE

Marine science is the branch of science concerned with the sea. It is an extremely broad discipline and marine scientists can work in areas as diverse as marine biology, geology and geophysics, zoology and environmental protection. It is said that the history of marine biology might have begun as early as 1200 BC when the Phoenicians took to the ocean, but it wasn't until Aristotle that references to marine life were recorded. Indeed, Aristotle is often referred to as the father of marine biology.

Captain James Cook mapped much of the world's unchartered waters in the 18th century, while Charles Darwin went on several expeditions on the HMS Beagle from 1831 to 1836. This led to the publication of the Origin of Species, where his theories of natural selection and evolution were formulated. These days, marine scientists tend to be more focused on specific research aims, including Karyna who uses molecular techniques to identify viruses in environmental samples.

WHAT DOES KARYNA FIND MOST REWARDING ABOUT HER WORK?

Karyna specialises in a technique called viral metagenomics, which allows her to target all the genetic material from viruses found in any given sample. By circumventing techniques that target specific viruses, such as the polymerase chain reaction (PCR), Karyna's research has often led to the discovery and detection of unsuspected viruses. She explains, "PCR is like fishing one fish at a time, using bait that works for certain types of fish, whereas viral metagenomics is like using a giant net – you never know which 'fish' you're going to catch!"

She enjoys hunting for viruses in a variety of environmental samples (from wastewater, to seawater, to air) and organisms (mainly invertebrates and plants) and says collaboration is one of the main appeals of her work. "I get to work with scientists from different backgrounds who are interested in learning about viruses in their study systems – it is always exciting to discover new viruses and contribute to new knowledge," says Karyna. "In addition to research, I really enjoy working with students in the lab and seeing them develop as scientists and professionals."

WHAT ARE THE MOST SURPRISING THINGS ABOUT VIRUSES?

With the shadow of the coronavirus pandemic still hanging over the world, the public is paying more attention to viruses than it has done for some time. It might be surprising for you to learn that viruses are by far the most abundant biological entities on our planet and they affect all living organisms. "In our oceans, there are about 100 billion times as many viruses as there are grains of sand on Earth – next time you go to the beach you can think of how you are swimming in viruses, but don't worry – the majority of those infect microorganisms, not people," says Karyna. "I imagine most people don't get a warm feeling from such an image but it's worth knowing that there is an incredible diversity of viruses and there is much to learn about what they are doing."

WHAT ARE THE MOST PRESSING ISSUES FACING TODAY'S MARINE SCIENTISTS?

Karyna believes the most pressing issue is understanding the impacts of climate change on our oceans and designing mitigating strategies. "When we consider the trend of 'alternative facts' and science denial, science communication is becoming more and more important," says Karyna. "Scientists need to lead efforts to communicate with the public and learn how to do it effectively." It is essential that more people become aware of the dangers of climate change and explore potential strategies to mitigate these impacts.

HOW TO BECOME A MARINE SCIENTIST

- Career Explorer goes into great detail about the experience of being a marine biologist. From what they do, to the various job titles that fall within the field of marine science, through to some frequently asked questions, this website has it all. https://www.careerexplorer.com/careers/marine-biologist/
- Stanford Libraries has a comprehensive list of marine biology organisations and institutions in the US. Have a look through and head to the sites that are most specific to your particular interests. https://library.stanford.edu/hopkins/research-help/marine-biology-organizations-and-institutions
- The average salary for a marine biologist in the United States is $32,159. Wages typically start from $24,166 and go up to $71,561. https://www.careerexplorer.com/careers/marine-biologist/salary/

PATHWAY FROM SCHOOL TO MARINE SCIENCE

Karyna thinks it is important to have a broad base of science and maths courses under your belt, including chemistry, physics, calculus, biochemistry and statistics. "It would be advantageous to have some basic understanding of coding/informatics given that many of the technologies used today either need or produce large amounts of data that require computing power for analysis and visualisation," says Karyna. "In addition to courses, I highly recommend seeking research experiences. Hands-on experiences will help you figure out what you do and don't enjoy."

2 or 3 A levels, or equivalent.

You will usually need a degree that is relevant to the specific area of marine science you want to work in. Possible subjects include biology, chemistry, ecology, marine biology, oceanography, physics and zoology.

https://www.careerexplorer.com/careers/marine-biologist

HOW DID DR KARYNA ROSARIO BECOME A MARINE SCIENTIST?

WHAT WERE YOUR INTERESTS AS A CHILD? DID YOU ALWAYS WANT TO BE A SCIENTIST?

Growing up, I loved being outdoors and was curious about animals and nature. I never really thought about becoming a scientist – all I knew was that I really enjoyed biology, chemistry and genetics courses in school. I decided to enrol as a biotechnology major in college, where I found I still enjoyed science courses. After participating in a few research projects and learning about the microbial world, I was hooked forever!

WHO OR WHAT HAS INSPIRED YOU IN YOUR CAREER?

Over the years, I have been inspired by great mentors who are passionate about their science. There are too many to mention all of them, but what the following individuals have in common is a genuine interest in helping others succeed and, in one way or another, they gave me the tools (emotional and/or technical) to pursue a career in science. From my BS degree training I am thankful to Drs Vivian Navas Almeyda, Carlos Ríos Velázquez and Brian L. Bingham. From my MS degree, my advisors: Dr Raina Maier and Julie Nielson. During my PhD I was fortunate to meet Dr Arvind Varsani, a friend and collaborator. Last but not least, I have had the pleasure of working with Dr Mya Breitbart, whom I consider a fierce and selfless scientist, mentor and friend, for over ten years.

WHAT DO YOU THINK ARE THE KEY SKILLS AND ATTRIBUTES THAT A SCIENTIST NEEDS TO BE SUCCESSFUL?

If you are curious and enjoy learning and figuring out how things work, I think science is for you. Other important aspects are a willingness to work in teams, self-motivation, not being afraid of making mistakes and good communication skills.

WHAT AMBITIONS OR GOALS DO YOU HAVE?

We are living in strange times. As I write answers for this interview, there is a pandemic that threatens the life of every citizen around the world and climate change is quickly painting a dire scenario for future generations. I'm perplexed by the fact that some people think these pressing issues are hoaxes. The scientific endeavour is seemingly becoming less valued and respected. I hope to continue contributing to new knowledge with my research, while becoming a better advocate for bridging scientific discovery with the needs of our community.

HOW DO YOU SWITCH OFF FROM YOUR WORK?

When I am not working, I love spending time with family and playing with my sons. It doesn't matter what happens in the lab, good or bad, my boys just want to play, wrestle and run around! Being outdoors and exercising also helps me switch off from work.

KARYNA'S TOP TIPS

1. Try and discover what you find most exciting about your field of study as soon as you can and, once you have, never lose sight of it when things get complicated.

2. Studying and doing well in classes is important, but make sure you make room in your life for friends and family. They will support you in your quest for new life experiences. In my case, science facilitated new experiences that helped shape my academic and professional career, but family and friends have always remained important to me.

3. If you are interested in pursuing a career in science, please always keep in mind that there is no set path. Never count yourself out based on pre-conceived ideas of what a scientist's background should be!

Drs Erin Symonds, Mya Breitbart and Karyna Rosario at their 'World of Microbes' station as part of the St. Petersburg Science Festival (https://www.stpetescifest.org/).

Mya and Karyna collecting samples at the wastewater treatment plant.

WHY IS IT IMPORTANT TO STUDY LIFE IN THE DEEP SEA AND EVEN BELOW THE SEAFLOOR?

DR VIRGINIA EDGCOMB HEADS A LABORATORY AT THE **WOODS HOLE OCEANOGRAPHIC INSTITUTION** IN THE US. SHE SPENT THREE MONTHS ON A SHIP IN THE MIDDLE OF THE INDIAN OCEAN CONDUCTING RESEARCH AS PART OF A QUEST TO FIND EVIDENCE OF MICROBIAL LIFE WITHIN THE LOWER OCEANIC CRUST

Imagine being on an expedition in the middle of the Indian Ocean for three months, surrounded by azure skies and bottle green seawater, with no other vessels as far as the eye can see. That is exactly what Dr Virginia (Ginny) Edgcomb found herself doing when she was invited to be part of the International Ocean Discovery Program Expedition 360 between November 2015 and January 2016. Ginny is a microbiologist whose research spans across marine ecology. Her lab is based at the Woods Hole Oceanographic Institution in the US and she was on a research vessel – known as the *D/V JOIDES Resolution* – to explore evidence of microbial life below the ocean floor. "When most people think about the oceans, they think of the sunlit surface waters and charismatic megafauna such as whales and fish," explains Ginny, "but the most abundant organisms on Earth are not visible with the naked eye, and form the foundation of all major biogeochemical cycles throughout the water column and even below the seafloor." One of the most exciting aspects of the project was that she had no idea what the team would find, although she was hopeful that they would find some sign of life, past or present, in at least one sample!

The expedition, known as the Indian Ridge Moho Expedition, drilled approximately 850 metres into the Atlantis Bank gabbroic massif, which is igneous rock that formed when magma was trapped beneath the Earth's surface and cooled slowly. The unusual thing about this site is that this lower ocean crustal rock (typically thousands of metres below seafloor sediments and upper crustal rocks) is exposed at the seafloor at this site, allowing the *D/V JOIDES Resolution* to drill directly into it! Twenty-two scientists took part in the expedition – they included geologists, geophysicists and geochemists. Ginny, who worked alongside fellow microbiologist, Jason Sylvan from Texas A&M University, wanted to determine whether there were any signs of life down there.

WHAT METHODS DID GINNY USE IN THE COURSE OF HER RESEARCH?

The team used culture-based approaches, microscopy, molecular analyses of DNA, RNA and lipids, and enzyme assays, with each method telling its own story. "With current methods, scientists are only able to grow a small fraction of microbes from field samples in the laboratory," explains Ginny. "This means culture-based methods cannot recover the full extent of *in situ* diversity [diversity found in the natural place of origin]. But we can experiment with those that grow to learn what conditions they prefer/tolerate and what molecules they can use for their growth."

By analysing the DNA in samples, the team could learn what microbes (living or dead) are/were present and what genes they carry, while RNA analyses could tell them what genes they are expressing. Lipid analyses tell us about the identity and characteristics of microbes living or dead, depending on the lipid. Analyses of proteins enable understanding of what proteins were made by living cells, including enzymes. Enzyme activity assays indicate selected activities of living cells, while microscopy allows them to visualise and count cells. "Depending on the sample, some types of analyses are easier or harder, some fail and some are successful," says Ginny. "Together, they all build a picture of what microbes are or were in a sample."

WHAT WAS THE MOST EXCITING DISCOVERY?

The team detected intact cells in rock samples, which provided direct evidence that microorganisms are present – and remember that this is incredibly far below the ocean floor, in rock. When the team found culturable bacteria and fungi, as well as cellular enzyme activity, it was an indication that some of the cells the team observed were alive.

WHERE WILL THE RESEARCH LEAD TO IN THE FUTURE?

More crustal deep biosphere sites need to be

sampled to be sure that the samples the team took from the Atlantis Bank are representative of the lower crust. Another important aim is to use technology to sample subsurface fluids, and to collect and preserve rock material *in situ*, as opposed to bringing it to the ocean surface before preservation. This will minimise the chances of contamination and/or alteration of biomolecules during recovery and will provide a fuller picture of the life down there.

WHAT IS EVERYDAY LIFE ON AN EXPEDITION OF THIS NATURE LIKE?

The team had a routine that was virtually the same every day. "Each scientist works a 12-hour shift, the ship works 24 hours a day and you share a sleeping room with one other scientist on the opposite shift," explains Ginny. "Every time a core comes up to the ship, the same set of procedures must be performed. Meanwhile, laboratory reagents must be prepared, analyses performed, daily meetings held, meals are eaten, and if you are lucky, you find time to go to the gym or relax with colleagues, make a phone call home, and still get enough sleep!"

DR VIRGINIA EDGCOMB

Geology and Geophysics Department
Woods Hole Oceanographic Institution
USA

FIELD OF RESEARCH

Marine Microbial Ecology

RESEARCH

Ginny was part of the International Ocean Discovery Program Expedition 360, where she collected samples from the Atlantis Bank to see if there was evidence of microbial life.

FUNDERS

National Science Foundation (NSF), NASA

BIOCHEMISTRY AND MARINE ECOLOGY

Paraskevi (Vivian) Mara works as a postdoctoral investigator at Ginny's lab. She shares her experiences with us:

Can you tell us a bit about your role and how biochemistry contributes to marine ecology?
I am a biologist and work with microbes from extreme environments. Biochemistry is a bridge between biology and chemistry, and can be placed in the context of any science that studies life or the relationship of organisms with their physical surroundings (such as seawater). Part of what I do involves investigating expression of genes responsible for the biochemical reactions that happen in microbes.

Who inspires you in your work?
I am blessed to be working with a bright scientist, Dr Edgcomb, who is also my mentor. I am inspired by her intelligence, strong will, fair and unbiased judgment, and her enthusiasm for science, and by the fact that she is open to giving opportunities to people around her. Another person who has had a crucial role in my studies is Professor Eleftheriou, who was my first principal investigator when I was still in Greece. Although he retired years ago, he is still an active marine researcher! He has taught me many things.

What advice would you offer someone wanting to follow in your footsteps?
I would advise younger students to improvise and think outside the box when it comes to science. Also, choose a supervisor based on a combination of criteria, not only by scientific achievements and published papers. It is really important to have a good mentor who can help you mature and make you a better person along the process of scientific maturation.

ABOUT MARINE ECOLOGY

Marine ecology is the scientific study of marine life, including habitats, populations and the interactions between organisms and the surrounding environment. Marine ecologists perform a wide range of tasks that are all broadly related to the ocean. Some projects, like the one that Ginny was part of, pay particular attention to a specific area, while others consider wider issues, such as the impact that human activity is having on marine life.

Understanding marine ecosystems is vital, not least because of society's reliance on them for food security, materials for medicines and defence against natural events. Marine ecosystems are essential to sustain life on Earth as we know it, so marine ecologists perform extremely important research with practical implications (alongside the beauty of simply finding out more about things).

WHAT DOES GINNY PARTICULARLY ENJOY ABOUT THIS AREA OF RESEARCH?

Ginny finds the discovery of life in extreme habitats especially exciting. "Exploring the limits of life is fascinating – microorganisms seem to find a way to live under the most inhospitable conditions. Unusual habitats reveal microbes that can produce new biomolecules for medicine and industry," says Ginny. "Because the deep biosphere is so extensive, even low levels of activity and low cell numbers can equate to significant impacts on carbon and other nutrient cycling on Earth."

WHAT ARE THE PRESSING ISSUES FACING TODAY'S MARINE ECOLOGISTS?

As with many other scientific (and non-scientific) fields, climate change is a significant issue. "The speed at which the climate is changing and other human-influenced changes to the ocean are occurring is a major problem," says Ginny. "There are also severe limitations on federal government research funding to do the work necessary. Environmental research simply must – and I believe it will have to – become a national priority."

HOW DOES COLLABORATION WITH OTHER RESEARCHERS FACTOR INTO GINNY'S WORK?

The focus of Ginny's studies necessitates close collaboration with scientists from a broad range of disciplines. Each has their own unique vocabulary and brings differing perspectives and priorities to the big questions. "Planning, communicating and coordinating interdisciplinary work can be both challenging and exciting," says Ginny. "By looking at a set of samples, using different expertise and a variety of methods, we gain a much deeper understanding of those samples."

HOW TO BECOME A MARINE ECOLOGIST

- Study.com has a page dedicated to marine ecology, including a job description, duties and some of the academic requirements. It contains a wealth of useful information for those interested in pursuing a career in field.
- The Marine Conservation Institute (MCI) has interesting info for budding marine ecologists, including an interview with the President and CEO of MCI.
- According to career websites and Ginny, there is quite a range when it comes to salaries, depending on the level you are at and your location. Entry level salaries can start in the $30,000 to $40,000+ range for scientists with undergraduate degrees, while more experienced marine biologists can earn well over $80,000 a year. It's a career with financial, as well intellectual, rewards.

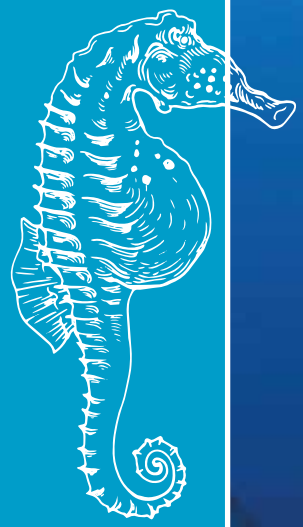
PATHWAY FROM SCHOOL TO MARINE ECOLOGY

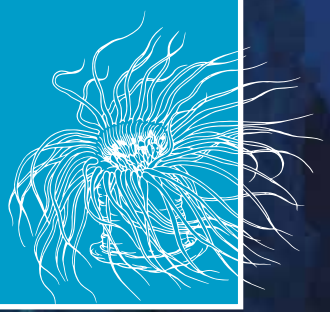
As Ginny's experience demonstrates, there is no single pathway to marine ecology. Her undergraduate degree was in finance before she decided to return to college and then university. So, remember – it is never too late to do what interests you most!

Ginny doesn't think it is especially beneficial for high school students to take specialised courses in sciences at the expense of core classes. "A good scientist has a broad knowledge base, is a critical thinker, creative and a good communicator," explains Ginny. "This requires a broad range of skills and knowledge, and a solid and broad foundation in the sciences and maths is essential. There's lots of time for specialised classes in college and university"

Marine ecologists may find entry-level positions with just a bachelor's degree, but a post-graduate degree is necessary for independent research positions. Relevant fields of study include biology, oceanography, environmental studies, biochemistry, policy, and natural resource management.

https://study.com/articles/Marine_Ecologist_Job_Description_Duties_and_Requirements.html





HOW DID DR VIRGINIA EDGCOMB BECOME A MARINE ECOLOGIST?

DID YOU ALWAYS WANT TO BE A SCIENTIST?

I was always interested in nature. My parents and I spent a lot of time hiking, fishing, observing birds and gardening. My mother started the first recycling programme in our township and was an avid environmentalist. I think this is where I learned that an individual could make a difference. When I got to high school and college, environmental science was my favourite subject and I knew that, ultimately, I wanted to contribute to addressing questions related to the interface between climate change, habitat loss and biology. A few years after my undergraduate degree in finance, I returned to college to focus on this by completing core science requirements and applying to graduate school.

WHICH ATTRIBUTES HAVE MADE YOU SUCCESSFUL AS A SCIENTIST?

It has helped me to be passionate about the process of discovery and conveying the importance of addressing climate change. It has also helped me to be collaborative, honest, and generous with my ideas and my time toward mentoring younger scientists.

WHO OR WHAT HAS INSPIRED YOU IN YOUR CAREER?

I was lucky to be mentored by three amazing men early in my career. The first was my postdoc mentor, Mitchell Sogin, who provided my most valuable learning opportunities in and outside of the lab, and whose confidence in me was so important to my development as a scientist. The next was my second postdoc mentor, Andreas Teske, who showed me what passion for science, and microbiology in particular, really is. My most recent mentor was the late Edward Leadbetter, a retired microbiologist with tremendous knowledge and patience, who worked on his projects in my laboratory, yet managed to encourage my continued learning and critical thinking. Three female scientists at Woods Hole Oceanographic Institution also helped me tremendously by serving as successful female role models. Before I had my own lab, they each provided me with space to work in their labs; they gave me helpful advice and collaborative opportunities. They are Joan Bernhard, Karen Casciotti, and the late Katrina Edwards.

WHAT ARE YOUR PROUDEST ACHIEVEMENTS?

I am most proud of the papers I have published that have students or junior researchers as the lead authors. These are projects that I mentored, that I was passionate about, but that these people took the lead on.

HOW DO YOU 'SWITCH OFF' FROM THE PRESSURES OF YOUR WORK?

This is a skill everyone has to learn – and I learned this slowly, I'm afraid. Hours are needed in each day for yourself, for family and friends, during which there should be no email or other interruptions. I take walks in the woods or on the local beaches, I get together with friends, ride my bike, paddle my kayak, work in my garden or just enjoy my porch. When I can, I travel. Taking breaks out of your day helps you to be healthier and more productive.

GINNY'S TOP TIPS

1. Get as many hands-on experiences as you can, as early as possible. Volunteering or working during the summer for different laboratories at different institutions can help you achieve this, but there are also internship opportunities out there. Fellowships can help fund the summer work if you can get them.

2. Talk to as many scientists as you can, whenever you get the opportunity! This will help you learn precisely what excites you and why – from there you can start to refine your interests and define what you want to do in your career.

3. I found several courses particularly useful at the college level, including writing and public speaking courses. Both could stand you in good stead in the future. Take as many chemistry classes as you can, maths (particularly statistics), and microbial ecology and microbiology. If you want to study the marine environment, take a biological oceanography course.

Field work during the International Ocean Discovery Program (IODP) Expedition 360 to Atlantis Bank, Indian Ocean. Ginny is working inside a walk-in laminar flow hood to process rock samples. Photo by Jason Sylvan.

HOW CAN UNDERSTANDING PLANTS AND MICROORGANISMS HELP FEED THE WORLD?

DR DAVIDE BULGARELLI, A SCIENTIST OF THE UNIVERSITY OF DUNDEE, BASED AT THE JAMES HUTTON INSTITUTE IN SCOTLAND, IS STUDYING THE INTERACTION BETWEEN PLANTS AND SOIL MICROBES. THE FINDINGS COULD BOOST SUSTAINABLE FOOD PRODUCTION AND HELP ACHIEVE GLOBAL FOOD SECURITY

By 2050, the global population is expected to increase to 9.8 billion and, by 2100, 11.2 billion. Such numbers are concerning because there will be billions more mouths to feed and current farming and agricultural processes are considered inadequate to cope with this increased demand. With this in mind, researchers are turning their attention to developing novel strategies that will enable crops to be grown in a sustainable way to ensure global food security.

To develop these strategies, it is vital that plant scientists conduct investigations to understand more about plants and how they interact with their environment and other organisms. Dr Davide Bulgarelli, a researcher of the University of Dundee based at the James Hutton Institute in Scotland, is a plant scientist who is studying interactions between plants and soil microbes. It is hoped that by understanding how plants communicate with bacteria in soil, it may be possible to manipulate these interactions for the benefit of plants and improve crop yields.

WHAT IS THE SPECIFIC FOCUS OF DAVIDE'S RESEARCH?

In one current project, Davide and his team are focused on understanding more about barley – the fourth most cultivated cereal crop in the world. It is known that plants and animals do not exist alone, but rather interact with different microorganisms, known as the microbiota. There are millions of different bacteria in the soil clumped around plant roots, in what scientists call the rhizosphere, and Davide wants to understand the role of microbiota in the rhizosphere. "The rhizosphere microbiota can help plants to grow better and healthier," explains Davide. "It is, therefore, fair to say that the rhizosphere microbiota is a key determinant of global food security."

WHAT METHODS AND TECHNIQUES HAVE DAVIDE AND HIS TEAM USED IN THEIR INVESTIGATIONS?

Because the microorganisms that Davide and his team are studying are invisible to the naked eye, they need to use state-of-the-art techniques to aid their investigations. One means of doing this is to study the DNA of microbes. DNA can be thought of as a blueprint for every living organism. "Like a 21st century microscope, state-of-the-art sequencing technology allows us to look inside microbial cells and identify building blocks of the DNA blueprint, which scientists call genes," says Davide. "Each gene has its own 'signature' called a sequence and this varies depending on the organisms we are looking at. It is like a fingerprint: a given gene or a given gene sequence can be used as a proxy for a given microorganism."

Using these techniques, Davide is able to understand which microbes are in the soil and what they can do. The team can then compare this information with other microbiota in different crops and soils to gain a fuller picture of the relationship between plants and soil microbes.

WHAT HAS THE STUDY REVEALED ABOUT HEALTHY PLANT MICROBIOTA?

One of the key findings of the team's work is that there is no one-size-fits-all scenario when it comes to the plant microbiota. Every crop has its own microbial signature, where a set of microbes can colonise the rhizosphere and other plant tissues. "One useful way of looking at our findings is to think of the plant as the conductor of an orchestra," says Davide. "It fine tunes the composition of the individual microbial members of the microbiota – if we can understand the music sheets, we can

DR DAVIDE BULGARELLI

School of Life Sciences, University of Dundee at the James Hutton Institute Scotland, UK

FIELD OF RESEARCH

Plant Sciences

RESEARCH

Davide's research is concerned with studying the interaction between plants and soil microbes. The ultimate aim of his work is to boost sustainable food production and contribute to global food security.

FUNDER

Biotechnology and Biological Sciences Research Council (UKRI-BBSRC)

DAVIDE'S TOP TIPS

01 – Any scientific career starts with having a natural curiosity and passion for scientific discoveries, so if you have those, you are already on the right path to becoming a scientist. Such qualities can help motivate you when you face difficult times or unexpected setbacks.

02 – Always listen to advice. You cannot do this on your own, so speaking with people who have already experienced the things you are experiencing can be invaluable in preparing you. However, you should be in control of your own choices – you have to do what is right for you.

03 – Be prepared to make sacrifices along the way. Sometimes you need a change of scenery to realise your career ambitions and achieve your objectives. This could even mean moving to another country.

predict what tune needs to be played to grow a healthy crop in a given soil."

HOW COULD FINDINGS FROM DAVIDE'S TEAM HELP WITH SUSTAINABLE CROP PRODUCTION?

By developing understanding of how plant genes shape the rhizosphere microbiota, Davide's studies will enable plant breeders to select crops that are better suited to engage in beneficial interactions with soil microbes. Importantly, these crops will be less reliant on chemicals to boost growth, so will be more sustainable.

Another important aspect of the research in Davide's lab is the study of ancient varieties and wild relatives of crops. We must remember that the crops we grow today are a result of centuries upon centuries of domestication and selective breeding – these human-made selections have led to more productive crops, but perhaps this has come at the expense of beneficial plant-microbiota interactions. "More often than not, what happens below ground, such as plant-microbiota interactions, does not feature in plant breeding schemes," says Davide. "By looking at the microbiota of wild relatives of crops, which have evolved under marginal soil conditions, we could identify plant-microbe associations that were left behind during domestication."

Davide hopes to uncover information that has been lost to plant breeders over time and that, coupled with his work on barley crops, could help lead to a more sustainable future for crops and global food security.

An example of the rhizosphere surrounding the roots of a young barley plant.

ABOUT PLANT SCIENCES

Plant sciences, which was once more often known as botany, is the systematic and scientific study of plants. Researchers in the field focus on the structure and biochemistry of plants, the physiological processes that happen in them, and their relationship with the surrounding environment and other organisms.

The history of plant science is long and varied. Aristotle is said to have done work in identifying plants in 400 BC and is seen as the originator of the scientific study of life, but it wasn't until the 17th century that plant science became a significant field of study. In the late 17th century, Robert Hooke contributed to the building of one of the most elegant – and effective – microscopes, which provided a means of investigating cells and eventually led to the discovery of single-celled organisms.

Davide highlights three key historical figures in plant sciences who provide inspiration for his team's current work and are worthy of further reading:

- Gregor Mendel was a 19th century monk whose pioneering work in genetics, using peas, now forms the basis of Davide's day-to-day investigations.
- Barbara McClintock is another innovative plant geneticist. She discovered the 'jumping genes' of maize and was awarded a Nobel prize for work in this field (in 1983).
- Norman Borlaug conducted research that formed the basis of the 'Green Revolution' – research that led to increased agricultural production worldwide. He was awarded the Nobel Peace Prize in 1970 – the first of many accolades he received.

WHAT ARE THE MOST PRESSING ISSUES FOR TODAY'S PLANT SCIENTISTS?

Although the work of Norman Borlaug was instrumental in tackling hunger around the world, hunger and malnutrition are still issues for many parts of the world today and the challenge for a fair and sustainable future is still on. The ever-increasing global population will continue to stretch resources around the world and plant science is seen as one of the most effective ways of overcoming these challenges. "By 2050, agricultural production will need to more than double to ensure there is enough to feed everyone," explains Davide. "Current approaches are not sufficient or sustainable, so it is vital that we can develop novel strategies to ensure a fairer and safer future for everyone." Understanding how plants function in the environment is fundamental to designing these strategies.

PLANT SCIENCE IS HIGHLY MULTIDISCIPLINARY. HOW IMPORTANT IS COLLABORATION TO RESEARCH?

Davide says that he cannot imagine a working environment without the types of interactions he is engaged with on a near-daily basis. His research involves working with many partners from several countries across Europe and the rest of the world, and these collaborations are extremely important to the success of his project. "Engaging with different life and working experiences provides you with different visions on science," says Davide. "This is exactly what you need when you are working to overcome a difficult situation and trace new paths in the course of your research."

WHO OR WHAT HAS INSPIRED DAVIDE IN THE FIELD OF PLANT SCIENCE?

Davide grew up in an agricultural area and always valued the importance of food. However, it wasn't until he was in his third year at university that he really began to consider a career in plant sciences. "Back then, I had to take an internship outside of the faculty and I was lucky enough to end up in one of the top-level plant sciences research institutes in my country," explains Davide. "The camaraderie among scientists, the scientific debates, the thrill of a new scientific discovery … it all suddenly clicked and I realised that was what I wanted to be part of and study for the rest of my academic life!"

HOW TO BECOME A PLANT SCIENTIST

- Science and Plants for Schools (http://www.saps.org.uk/) is an organisation that promotes plant science at school level. It includes a wealth of information about how to go on to study it at university and has a range of science clubs documenting student activities (http://www.saps.org.uk/secondary/science-club-activities).
- The UK Plant Sciences Federation (http://www.plantsci.org.uk/) forms part of the Royal Society of Biology. It promotes the importance of plant science and how it benefits society, and provides a forum for discussion, debate and information exchange.
- Plant scientists can earn between £22,000 and £55,000 per annum, depending on their level of experience. Salaries of more senior professionals, such as university professors or leading scientists at major agro-biotech companies, may exceed these figures.

HOW DID DR DAVIDE BULGARELLI BECOME A PLANT SCIENTIST?

DID YOU ALWAYS KNOW YOU WANTED TO BE A SCIENTIST OR DID YOU HAVE OTHER AMBITIONS?

When I was a kid, I played with LEGO a lot of the time! I wasn't always indoors, though – I still have memories of playing seemingly never-ending ball games with my friends. At that time, becoming a scientist wasn't something I ever really considered – I think becoming a professional sportsman was my first career choice. Over time, as that dream became more and more unlikely, I was drawn to science and, eventually, got into the field of plant science. If I hadn't become a scientist, I honestly don't know what I would have done.

WHAT ATTRIBUTES HAVE ENABLED YOU TO BECOME A SUCCESSFUL SCIENTIST?

I think it is worth highlighting that there isn't a perfect or unique recipe to guarantee success. In my career, I have learned that it is important to stand up for yourself and take setbacks on the chin; they shouldn't be thought of as a dead end, but as a starting point for a path to new achievements. You should listen to advice, but be in control of your own choices where possible – these points have certainly been the main drivers behind my career.

HOW DO YOU OVERCOME ANY OBSTACLES AND FRUSTRATIONS YOU FACE?

Sometimes you just need to unplug yourself for a day. Once you return, the problem may well still be there, but it is possible you will see a new solution that you were unable to see before. Seeking advice from colleagues who have experienced similar situations has helped me a lot in the past.

DO YOU HAVE AN OVERARCHING CAREER AMBITION?

Yes! Ultimately, I hope that my team's work will contribute to achieving global food security – that is my main motivation and career ambition.

FINALLY, WHAT INTERESTS DO YOU HAVE OUTSIDE WORK?

I still play football, although it tends to be with my colleagues now rather than the friends I played with as a child! I am also an avid reader of crime novels, so I read those whenever I get the chance. I love travelling with my family, too.

A barley field with the river Tay in the background.

PATHWAY FROM SCHOOL TO PLANT SCIENTIST

Davide says that plant sciences clicked for him when he was at university, but that a good starting point for a career in plant sciences is developing a curiosity for disciplines like biological sciences, mathematics and genetics.

2 or 3 A levels, or equivalent, including biology

A degree in botany, ecology, environmental science, plant biology or plant science

https://nationalcareers.service.gov.uk/job-profiles/botanist

A RED-BLOODED PASSION FOR THE GREEN-FINGERED

DR CHRIS MARBLE IS AN ENVIRONMENTAL HORTICULTURIST BASED AT THE **UNIVERSITY OF FLORIDA** IN THE US. HIS WORK FOCUSES ON DEVELOPING WAYS OF IMPROVING WEED CONTROL IN VARIOUS SETTINGS. THE FINDINGS COULD BENEFIT FARMERS AND GARDENERS AROUND THE WORLD

The dictionary defines a weed as a, 'wild plant growing where it is not wanted and in competition with cultivated plants'. People who are considered feeble have been insulted as 'weeds', while to 'weed out' is to remove something from where it is not wanted. The connotations of weeds are almost exclusively negative and with good reason – they are the bane of budding gardener's lives all around the world.

Such is the extent of interest in finding ways to remove weeds that the US even has its own Weed Science Society of America – an organisation dedicated to understanding the impact of weeds on ecosystems. This interest in weeds and how best to control them is something that Dr Chris Marble can appreciate – he has dedicated most of his professional life to studying weeds, and specialises in invasive weed management. Based at the Mid-Florida Research & Education Center within the University of Florida in the US, Chris is currently working on a project that seeks to improve weed control in ornamental nurseries, greenhouses and landscapes.

WHAT ARE THE MAIN PROBLEMS WITH CURRENT WEED CONTROL PRACTICES?

Hand weeding is a common means of controlling weeds and, as the name suggests, it involves uprooting weeds by hand or with tools. While this method is relatively successful, it is extremely time-consuming and expensive. Then there is the use of herbicides to kill the weeds – again, a successful method, but one that can cost thousands of dollars per year. The knock-on effect of these methods is a significant reduction in profits and the overall sustainability of the industry. This is something that Chris and his team want to address in their research.

WHAT CHALLENGES DID THE PROJECT POSE FOR CHRIS AS A HORTICULTURIST?

The biggest challenge for Chris is trying to come up with ways to improve weed control that can be implemented across many different nurseries. "A field crop grower might grow one crop, like corn or soybeans or peanuts. In contrast, a nursery (ornamental plant) grower might have 500 different plants that they have to grow," explains Chris. "Many of these will require different fertilisation, irrigation, pruning, etc. They will also have to use different pesticides for many of those plants. Coming up with something that works for everyone is very difficult."

WHAT STRATEGIES DID CHRIS DEVELOP AND IMPLEMENT IN THE PROJECT?

The team has been researching how things like fertilisation practices, potting soils and irrigation scheduling can be changed in order to reduce weed growth and encourage highly marketable plants. Chris's concerns revolve around implementing strategies that are environmentally friendly and consider the bigger picture. Part of this approach explains why the team wants to try and alter production practices to increase the

DR CHRIS MARBLE

Ornamental, Landscape and Invasive Weed Management, Mid-Florida Research and Education Center, University of Florida, USA

FIELD OF RESEARCH

Environmental Horticulture

RESEARCH

Chris's research is focused on improving weed control in ornamental nurseries, greenhouses and landscapes. The findings will benefit all those who have a problem with weeds.

effectiveness of herbicides and therefore reduce the total amount of herbicide that is needed.

After thinking of new strategies, Chris and his team test them out in the lab under controlled conditions. If they work, they test them in the field, to make sure they work in the 'real world'. "We want these strategies to work for growers across the globe, so it is important to test them out in a variety of different environments," says Chris. "We also do on-farm research experiments with other researchers across the US."

WHAT HAVE BEEN THE MOST SIGNIFICANT FINDINGS?

By altering the placement of fertiliser and the physical properties of the potting soil, the team has managed to reduce weed growth. The reason this is important is that it is a relatively simple strategy and one that can be adopted by growers who are unable to use herbicides.

The next step is to apply the findings to real-life situations. Chris is aware that which of his team's findings will be adopted is heavily dependent on the particular nursery. "Some nurseries are more likely to adopt changes in their preemergence herbicide programmes based on our research," explains Chris. "There will be others who might find using mulch or altering fertiliser placement most beneficial."

A propagation house at a large commercial nursery operation.

Example of a greenhouse experiment investigating how liverwort (Marchantia polymorpha) spreads and grows on different nursery potting soils.

ABOUT ENVIRONMENTAL HORTICULTURE

Humans have been gardening for thousands of years. According to *Britannica*, western gardening had its origins in Egypt around 4,000 years ago[1] (although the practice of cultivating plants has certainly existed for much longer, with some reports suggesting 10,000 years).[2] However, it wasn't until 1806, when the Horticultural Society of London was established in England, that horticulture was viewed as a science.

In the centuries since then, a raft of degrees, masters and PhDs, centres, programmes, universities and other institutions have been created. Chris is a faculty member at the University of Florida's Mid-Florida Research and Education Center which has a stated mission of profitable yet environmentally responsible production and use of high-value horticulture plants and plant products to satisfy demand driven by consumer tastes, preferences, and wellness.

Imagine being fascinated by plants and the science of them and working with them every day of your professional life! It is a dream that Chris has made reality.

WHAT DOES CHRIS FIND MOST REWARDING ABOUT HIS RESEARCH?

Chris says that the most challenging and rewarding aspect of his work is the fact that he does not work on one or even a few different types of plant. "We work with thousands of different types of plants – succulents, flowers, herbs, medicinal plants, shrubs, trees. You name it and someone in environmental horticulture is working with that species," says Chris. "This diversity keeps things exciting and allows us the chance to work with and help many different kinds of people and industries."

However, while Chris loves that part of his research, he is keen to emphasise just how much he enjoys working with students. "Being able to help students develop new skills, learn about horticulture, science and research, and then watch them advance and be successful in their own right is why I do what I do," says Chris.

WHAT WOULD CHRIS'S DREAM WORK PROJECT BE?

Chris is unequivocal in his belief that he already gets to work on his dream project every day. One of his main passions is helping growers and the landscape industry solve real-world weed management challenges. Every day provides something different, whether it is a new weed, a new invasive plant or a different management scenario, and finding ways to solve these problems is what he wants to continue doing long into the future.

WHAT ARE THE MOST PRESSING ISSUES FACING TODAY'S HORTICULTURISTS?

Somewhat surprisingly, student enrolment in horticulture programmes is decreasing at some universities. Chris thinks there are many reasons for this but believes that those within academia and industry need to do a better job at demonstrating just how many different career opportunities there are within the sector. "Do you like art? Then get involved with landscape and floral design! Enjoy business, sales, or marketing? Many large nurseries and horticultural product companies have large sales and marketing teams!" says Chris. "There are countless opportunities for you in horticulture and plant sciences."

Chris loves what he does; many of you would find a career in horticulture rewarding too. Which route will you explore?

[1] *www.britannica.com/science/gardening/Choice-of-plants*

[2] *https://hort.purdue.edu/newcrop/originhorttech.pdf*

HOW TO BECOME AN ENVIRONMENTAL HORTICULTURIST

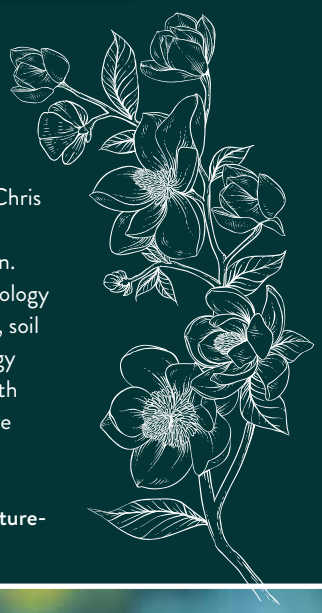
- The American Horticultural Society is one of the best resources out there for aspiring horticulturists. https://ahsgardening.org/
- This article in Guardian Careers discusses Sarah Chesters' experience of changing to a career in horticulture. It provides some handy hints and tips. https://www.theguardian.com/careers/couture-to-compost-blossoming-career-horticulture
- The average salary for a horticulturist in the US is $67,505 although this is highly dependent on the specific area you work in. Wages typically start from $35,208 and go up to $129,429.

PATHWAY FROM SCHOOL TO ENVIRONMENTAL HORTICULTURE

2 or 3 A levels, or equivalent.

Environmental horticulture is such a broad subject that Chris is keen to emphasise that the pathway you should take is highly dependent on the specific area you want to work in. "Some biology, physiology, environmental sciences or ecology subjects would all be helpful, but on a more specific level, soil sciences, plant sciences and then subjects like entomology or pathology would help if you wanted to work closely with plants," says Chris. "Business courses, like accounting, are great if you want to own your own business some day."

https://www.hortweek.com/career-horticulture/horticulture-careers/article/1523703



HOW DID DR CHRIS MARBLE BECOME AN ENVIRONMENTAL HORTICULTURIST?

WHAT WERE YOUR INTERESTS AS A CHILD? DID YOU ALWAYS KNOW YOU WANTED TO BE A SCIENTIST?

I enjoyed the regular stuff like playing sports and playing outside, seeing what I could get into. In high school, I was more interested in subjects like history and literature and my interest in science didn't really start until I went to college.

HOW DO YOU 'SWITCH OFF' FROM WORK?

I switch off by lifting weights, running and doing anything that is 'mindless', like doing chores around my home. I love to work in my garden, growing vegetables, and cooking. I also read three or four books per month, all non-fiction.

WHO OR WHAT HAS INSPIRED YOU IN YOUR CAREER?

My biggest influencers were my advisors in graduate school who taught me how to be a scientist. I have also had the opportunity to work with, and for, some great scientists who taught me a lot. Being at the University of Florida, I am inspired every day by the people I get to work with right down the hall from my office.

WHAT ARE YOUR PROUDEST ACHIEVEMENTS?

My proudest achievements are all my students' achievements – both while they are working with me and then after they graduate. Nothing I do would be possible without their hard work and the commitment of all the other staff in my programme.

WHAT NON WORK-RELATED GOAL IS AT THE TOP OF YOUR 'BUCKET LIST'?

Most of my goals are work or career oriented. Some bucket list items would be visiting every US state, running an ultra-marathon and learning Spanish!

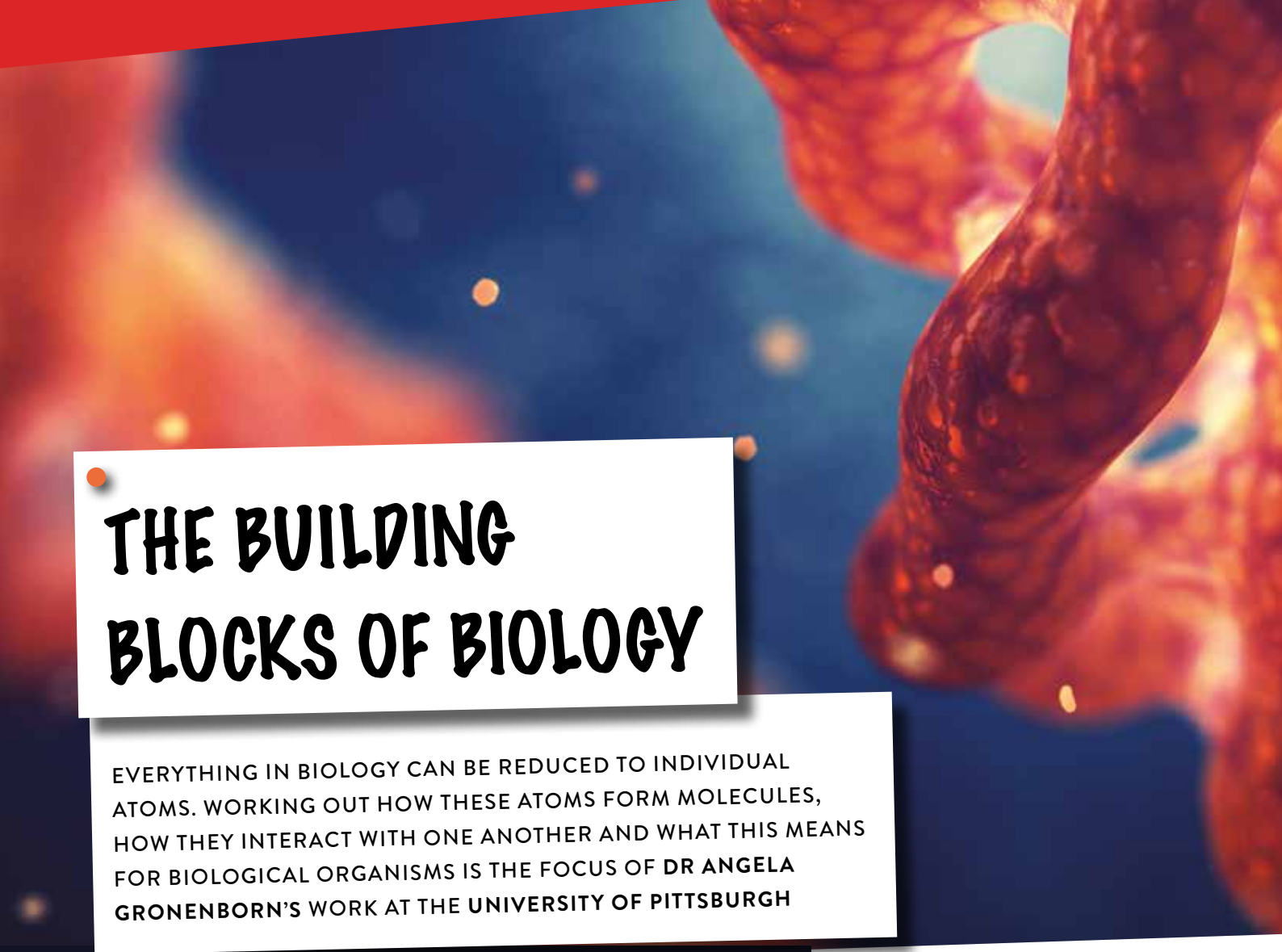
CHRIS'S TOP TIPS

1. If you want to work in academia, you really need to learn to love to write. Writing is the lifeblood of an academic, but you will be writing about subjects that you are very interested in.
2. Try and work on projects that interest you and you are passionate about. As a researcher, you are going to be putting in a lot of hours, but if you love the subject, it will never feel like work.
3. Whatever you can do to improve your communication skills and abilities will be extremely helpful in the sciences – or in any career you decide to pursue!

Chris teaching weed identification to pest management professionals.

An extension field day where Chris explains how herbicides can injure ornamental plants if they are not used correctly.

Examining a coleus plant that is infested with dodder (Cuscuta spp.), a parasitic weed.



THE BUILDING BLOCKS OF BIOLOGY

EVERYTHING IN BIOLOGY CAN BE REDUCED TO INDIVIDUAL ATOMS. WORKING OUT HOW THESE ATOMS FORM MOLECULES, HOW THEY INTERACT WITH ONE ANOTHER AND WHAT THIS MEANS FOR BIOLOGICAL ORGANISMS IS THE FOCUS OF **DR ANGELA GRONENBORN'S** WORK AT THE **UNIVERSITY OF PITTSBURGH**

TALK LIKE A STRUCTURAL BIOLOGIST

FLUORINE: A relatively light element that comes after oxygen in the periodic table. It is not often naturally present in organisms, particularly animals.

ISOTOPE: A variety of an element that has a different number of neutrons to protons. They may be written as (for example) carbon-13 or 13C, where the number refers to the sum of the element's protons and neutrons.

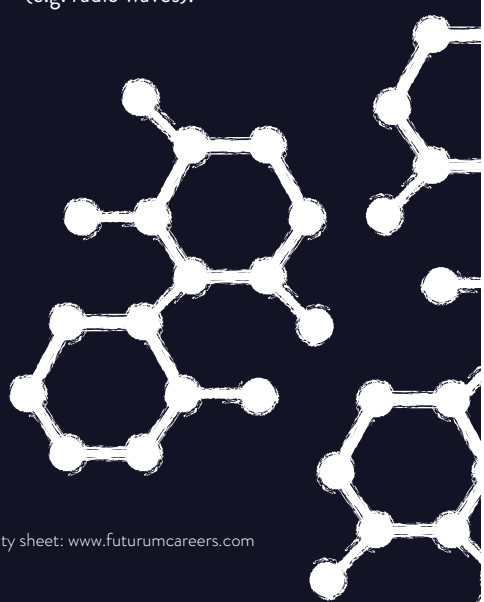
MACROMOLECULE: A molecule containing a very large number of atoms, such as a protein or nucleic acid.

NUCLEAR MAGNETIC RESONANCE SPECTROSCOPY: A type of spectroscopy that involves putting molecules in a magnetic field and recording the signal produced by excitation of the sample.

NUCLEIC ACID: The biomolecules that make up organisms' genetic code, i.e. DNA.

PROTEIN: A biomolecule made of amino acids, that are coded for by nucleic acids.

SPECTROSCOPY: A technique that involves studying the interaction of molecules and electromagnetic radiation (e.g. radio waves).



Uncovering the molecular interactions that govern biological cells is not straightforward. There are a range of techniques that structural biologists use to find out what is going on at the molecular level. Think of the analogy of the elephant and blind-folded people: each person can feel one part of the elephant – its trunk, its leg and so on – but only by communicating with one another can they get a sense of what the whole creature looks like. It's the same in structural biology: only through different teams of researchers, using different techniques and collaborating, can they get a sense of the bigger picture, and have an effective, positive impact on the world.

NMR SPECTROSCOPY

Dr Angela Gronenborn is an advocate of Nuclear Magnetic Resonance (NMR) Spectroscopy, a technique used to find out the structure of proteins and other molecules. Firstly, the target molecule is created with certain isotopes within its structure. Every isotope has its own magnetic identity and will vibrate at a certain frequency when exposed to a magnetic field.

ANGELA'S TOP TIPS FOR STUDENTS

01 Create your own path. Don't try to follow in anyone's footsteps.

02 Become a well-rounded person. As well as science, explore the humanities, literature and languages.

03 There is nothing wrong with failing; in fact, failing fast is the best. Then you can regroup and try again!

PATHWAY FROM SCHOOL TO STRUCTURAL BIOLOGIST

Angela recommends taking mathematics, physics and chemistry at school. Biology can also be useful, but isn't always essential – Angela does not have a biological background herself. She also advises seeking a well-rounded education, featuring literature and languages if possible.

At university, courses such as biochemistry, molecular biology, biomedicine, and other similar subjects can all lead to a career in structural biology.

DR ANGELA M GRONENBORN

UPMC Rosalind Franklin Chair and Distinguished Professor, Department of Structural Biology, University of Pittsburgh, USA

FIELD OF RESEARCH

Structural Biology

RESEARCH PROJECT

Investigating the applications of fluorine NMR spectroscopy as a technique for understanding structural biology.

FUNDERS

National Institutes of Health
National Science Foundation

NMR involves placing these samples within a strong magnetic field and recording the excitation patterns that the isotopes involved give off. These 'resonance frequencies' are recorded and used to identify the structure of the molecule. Once this information is collected, it undergoes complex analysis using sophisticated computational tools. The end product is a three-dimensional model that can be visualised and explored on a computer screen.

ISOTOPES AND FLUORINE

Isotopes are formed when an atom has a different number of neutrons to protons, a property that gives them a unique signature while still retaining all the element's normal chemical properties. A common way to get isotopes into the target molecule is to grow bacteria on isotope-rich nutrients so that they are incorporated into their biomolecules, which are then extracted. Common isotopes used in NMR include deuterium (hydrogen-2), carbon-13 and nitrogen-15, because these are accessible isotopes of the elements that are most common within organisms.

However, Angela's research uses fluorine-19 rather than the more conventional isotopes. Fluorine is not found naturally within biomolecules. "The overall goal of this research programme is to establish fluorine-19 NMR spectroscopy as a versatile approach for describing the structure and geometry of proteins," she says.

The main advantage of using fluorine is that it rarely suffers from background interference. Because isotopes of hydrogen, carbon and nitrogen are commonly found in nature, they often show up in NMR even when they're not part of the target molecule. Adding fluorine-19 to a molecule means that, if its resonance frequency shows up in analysis, it's almost certainly within the target molecule. However, because it is not a natural part of most biology, the researchers must be vigilant when adding it to molecules. "Each protein behaves differently and we always have to make sure that the molecule's folding pattern or its stability is not influenced."

REAL-WORLD APPLICATIONS

"The project involves an integration of computational and experimental approaches," says Angela. "We also plan to integrate scientific training with humanities, to help prepare students for communicating science to the public." The team hopes to demonstrate the usefulness of fluorine NMR as a technique to uncover important information that other techniques cannot.

Angela's team has already made headway using fluorine NMR to decipher proteins and small pharmaceutical molecules. This has some important practical applications. "We will use fluorine NMR to perform drug screenings, which should be very useful for drug design," she says. Angela hopes to use the technique on live cells, to be able to see what proteins are doing in real time.

The team has also found some unexpected effects, in particular regarding molecules' fluorescence properties – in other words, the radiation they emit. "There are always surprises," says Angela. "That is what's nice about science – there is always a new puzzle to solve."

ABOUT STRUCTURAL BIOLOGY

WHAT IS STRUCTURAL BIOLOGY?

Structural biology is the study of the molecular structure and interactions of biological macromolecules. In particular, it focuses on proteins and nucleic acids, which are responsible for the majority of complex and fundamental functions within cells. It's a field that incorporates aspects of molecular biology, biochemistry and biophysics.

LET'S ASK ANGELA:

WHAT DO YOU FIND MOST REWARDING ABOUT YOUR WORK?

"Every day there is a new puzzle," says Angela. "No two problems are alike and every time it's a case of working progressively towards the most likely explanation. This involves a lot of deduction: testing all possible explanations, and discarding them if they don't hold up, until you come across the one most likely to be true."

WHAT PERSONAL QUALITY DO YOU FIND MOST USEFUL FOR YOUR RESEARCH?

"I am very lucky in that I have a very good visual memory," says Angela. "So, once I have seen a protein model, I know what it looks like. Looking at a protein on a screen, turning it around and picking out every detail – it gets ingrained in my mind."

WHY IS AN INTEGRATED, COLLABORATIVE APPROACH SO IMPORTANT?

"Nature is complex and complexity needs to be addressed in its totality," says Angela. "With any method we use for viewing an object, we omit some of its features and only get a partial view. We need to integrate many such views to get closer to a more complete understanding. And, from a practical perspective, collaboration helps me do better science. We cannot be experts at everything, but by combining our areas of expertise, we can become unbeatable!"

WHAT LARGE-SCALE PROJECT WOULD YOU LIKE TO SEE BECOME REALITY?

"As structural biologists we would love to have a full 'movie' of a cell, and to see how it's affected by disease and other factors. We can then use our structural understanding to investigate the molecular pathways that have gone wrong, and work out solutions. That would be fantastic."

WHAT DO YOU THINK IS SCIENCE EDUCATION'S BIGGEST CHALLENGE?

"I believe all young children are naturally curious and could be attracted to science. Unfortunately, 'learning by doing' is a not a common approach in schools for teaching science, and this can mean basic scientific understanding is not attained by many. As scientists, we have to constantly try to educate those around us."

HOW TO BECOME A STRUCTURAL BIOLOGIST

- Structural biology is rarely an undergraduate course in itself, but its close cousins, molecular biology and biochemistry, sometimes are. Relevant material is often covered within wider biology and chemistry courses, too.
- According to UK News, the best UK universities for courses involving molecular biology and genetics are Cambridge, Oxford, University College London, Edinburgh and Imperial College London.
- According to US News, the best US universities for courses involving molecular biology and genetics are Harvard, MIT, Stanford, California (San Francisco) and John Hopkins.
- According to Payscale.com, the average salary for a molecular biologist is $59k.

MEET SCIENTISTS WHO HAVE WORKED WITH ANGELA:

NAIMA SHARAF

WHAT LED YOU TO BECOME A SCIENTIST?

As a child I had lots of interests, including solving jigsaw puzzles with my dad. My love of puzzles translates well to the lab, where I am tackling scientific puzzles daily. In high school, I wanted to be a psychiatrist, but my mum strongly advised I go into science. I chose to study chemistry, which seemed like a good challenge. I instantly loved it! Without my mother's push, I wouldn't be in science today.

WHAT WAS YOUR ROLE ON THIS PROJECT?

I was the primary author with Dr Gronenborn on a number of papers on fluorine NMR. My role was to incorporate fluorine-modified amino acids into proteins. I was able to use this to label an enzyme that's a major target for HIV treatment, and then study its reactions to inhibitors that could go on to become pharmaceutical drugs.

WHAT DID YOU FIND REWARDING ABOUT THE PROJECT?

I love fluorine NMR – the data were beautiful! It's free from

HOW DID DR ANGELA GRONENBORN BECOME A STRUCTURAL BIOLOGIST?

WHERE DOES YOUR PASSION FOR SCIENCE COME FROM?

I'm not exactly sure. At school, I was convinced I was going to be a mathematician, but the principal and my father cautioned me that it would be a difficult career as a woman. So, I decided I would study physics and chemistry. The real excitement came during my PhD when I was exposed to the new field of molecular biology by my biologist brother. I decided I would ultimately use my training in NMR to study biological systems, which was impossible at that time.

HOW DO YOU OVERCOME OBSTACLES IN YOUR WORK?

I am very stubborn and opinionated. I'll try and try again, even if something seems almost impossible. I become obsessed with a problem and cannot let it go.

WHAT DO YOU LIKE TO DO OUTSIDE OF WORK?

I do not need to switch off, because I don't see research as work. I am very fortunate that I get paid for doing my hobby! There are very few professions where one has such a privilege – artists perhaps, but compared to artists we get paid royally. However, I do enjoy art and music, and wherever I travel to give lectures, I make time to visit a museum.

WHAT ARE YOUR GOALS FOR THE FUTURE?

I hope that I can help my students achieve what they want to achieve. I have been extremely lucky in my career and I want to empower those trainees within my sphere of influence to find their own luck.

background signals and gives us lots of information about protein interactions.

WHAT'S NEXT FOR YOUR CAREER?

Next year, I will become a professor at one of two universities, along with my husband who's received similar offers from both. Now, we just have to decide which one!

WHO INSPIRES YOUR WORK?

My mum and Dr Gronenborn are great motivational figures. I am a mother of two young boys myself, and my mum acts as a role model for my work-life balance. Dr Gronenborn is a fantastic scientist as she works carefully and methodically, always making sure the data support the conclusions.

DO YOU HAVE ANY ADVICE FOR POTENTIAL FUTURE SCIENTISTS?

I would say go for it, and don't let people tell you what you can and cannot do!

CHRIS BARNES

WHAT LED YOU TO BECOME A SCIENTIST?

For a long time, I wanted to become a chef. I started cooking meals when I was 7 and really enjoyed the satisfaction of seeing people enjoy my food. In a way, being a chef encouraged me to be creative and 'experiment' with different recipes, which laid the groundwork for a scientific career.

WHAT WAS YOUR ROLE IN ANGELA'S DEPARTMENT?

When I was a graduate student, I worked on understanding transcription (the cellular process that makes proteins from amino acids). I explored the possibility of using fluorine NMR within a project, but it never moved out of the initial phase.

WHAT'S NEXT FOR YOUR CAREER?

I'm currently on the academic job market and am looking forward to starting my own lab at a leading research institution. I hope to research how to design drugs to target proteins involved in infectious disease. I hope that my future work will inspire the next generation of scientists, especially individuals of colour who may not feel like they belong in our field.

WHO INSPIRES YOUR WORK?

Broadly, Barack Obama is someone I admire and try to emulate. However, now I have children of my own, I find my parents are my main source of inspiration. Looking back, I now really appreciate how they provided me and my siblings with a great childhood.

DO YOU HAVE ANY ADVICE FOR POTENTIAL FUTURE SCIENTISTS?

I always make sure to let young scientists from under-represented minorities know that they belong. Representation matters and by taking part in initiatives to diversify STEM, I hope I show young scientists what they can become. In my own early career, I never saw another face that looked like mine and often questioned whether I belonged – it's an isolating experience. I think it's important to let young scientists know that they are not alone and that their feelings are real. I always remind them to take pride in their accomplishments – they earned it, after all.

DECODING THE RHYTHMS OF THE NATURAL WORLD

PATTERNS ARE EVERYWHERE IN NATURE, FROM SEASONS TO COLOUR SCHEMES TO HEARTBEATS. THE MORE YOU LOOK, THE MORE YOU FIND, AND THE MORE COMPLEX THEY BECOME. **DR BARD ERMENTROUT** OF THE **UNIVERSITY OF PITTSBURGH** USES ADVANCED MATHEMATICS TO DECIPHER THESE PATTERNS

TALK LIKE A MATHEMATICAL BIOLOGIST

EPIDEMIOLOGY
The study of how diseases spread and can be controlled.

LINEAR MODEL
A model is linear if changes in the inputs result in proportional outputs of the model.

NON-LINEAR MODEL
A mathematical model that does not follow a straight line on a graph. A model is non-linear if it is not linear!

PHENOMENA
Something observed, like a situation or event.

SPATIAL
Related to space.

TEMPORAL
Related to time.

The natural world is a complex place and being able to understand it requires complex tools. Dr Bard Ermentrout, Distinguished University Professor at the University of Pittsburgh in the USA, has plenty of expertise in applying these tools and learning exactly what the natural world has to tell us. Two of his recent projects involve understanding 'flicker hallucinations' and the mechanisms behind seashell colouration patterns.

FLICKERS OF UNDERSTANDING

Have you ever noticed how geometric shapes can appear in your field of vision when you're looking at flickering light? These 'flicker hallucinations' form an illusory pattern in your visual field, and Bard has undertaken research to understand exactly how and why this takes place. "Maths provides a framework for understanding many natural phenomena, and very different instances can lead to similar mathematical patterns," he says.

In a very different scenario, if you add oil to a warming frying pan and then evenly add pepper or paprika, the spice will separate into distinct geometric structures. Mathematical biologists call this 'spontaneous symmetry breaking'. It is the same general process that happens when the light uniformly hitting our eyes appears to break into distinct geometric shapes. "In terms of physics, there are big differences, but it's the same underlying mathematics," says Bard.

These processes occur when something 'loses stability'; it changes from a normal state (like the everyday function of our eyes) into something else. You can achieve this effect with all kinds of things. For instance, if moved, a pendulum will swing back and forth until it comes to rest. However, if you move the base of the pendulum a certain way at the same time, it will give the appearance of going haywire. It is the same principle as swinging your legs back and forth to go higher on a swing. Using mathematics to understand these unstable states when they occur in biology can reveal interesting secrets.

BREAKING IT DOWN

Studying flicker hallucinations can be challenging because the shapes are difficult to control and report. Bard's team managed to simplify the effect by reducing the flickering light to a thin ring. They were then able to quantify the effects they saw, ending up with data that could be mathematically processed.

Psychologists were also brought in to understand certain phenomena. "We noticed that the patterns on the ring of flickering light appeared to rotate, first one way and then the other," says Bard. Understanding how the brain processes visual information is critical to uncovering why these odd effects are seen.

So, what's the purpose of this research? One theory is that these shapes provide a window into early visual systems, in terms of in the first processing units in the cortex (the main part of our brains). These systems would interpret light or darkness as a simple 'on or off', which is perhaps why certain flickering lights appear to us as block geometric shapes. The patterns that we see are directly related to the way that the neurons are connected in this part of the

DR BARD ERMENTROUT

Department of Mathematics
University of Pittsburgh, USA

FIELD OF RESEARCH

Mathematical Biology

RESEARCH

Using mathematical models to uncover patterns in nature, such as visual hallucinations or pigments in mollusc shells.

cortex. Bard explains, "Given the connectivity, we can infer the patterns and, similarly, given the patterns, it is sometimes possible to infer the connectivity. As a famous example, if you put powder on top of a drum head and then you bow it on the side to cause a vibrating sound, there will be a pattern on the drum head that is directly related to both the shape of the drum and the tone of the vibration."

Experimentalists see many oscillations in the brain and these come in the form of waves that have been shown to reflect the connectivity between regions of the brain. "The patterns that we describe are at a much smaller scale, but follow the same principles," says Bard. Using mathematics to model these effects can build our understanding of not only human perception but also that of other organisms, present and past.

THE SCIENCE OF SEASHELLS

The principles of mathematical biology can be applied far and wide. Bard has worked with an evolutionary biologist to understand the complex patterns found on cone shells, a visually striking (and very venomous) family of marine molluscs. They found spontaneous symmetry breaking was the culprit again. "Uniform pigmentation became unstable, leading to stripes and other intricate patterns on the shells," says Bard.

The biological stimulus for this effect came from the mollusc's nervous system. As the shell grows, a simple neural network retains a 'memory' of the previous pattern and tells the pigment-producing cells to do the same again.

Ultimately, this research led to a better understanding of cone shells' evolutionary history, and even helped evolutionary biologists predict what the shells' ancestors would have looked like millions of years ago.

A MODERN SCENARIO

Mathematical biology and an understanding of patterns can also be used to tackle pressing modern issues. The COVID-19 pandemic is a prime example. Epidemiology involves complex maths to understand how viruses spread from one person to another, the roles of people without symptoms ('super-spreaders'), how the virus exists outside of the body and so on. Bard explains, "The spread of the virus depends on who the infected are connected to, so as with the brain patterns, the spread of the disease is directly related to who is connected to whom. The patterns reflect the underlying network." On a micro level, maths helps build models of the human immune system and the virus within it, which could help answer why some people are very deeply affected while others may not even know they are infected. Finding these answers is critical to saving lives.

ABOUT MATHEMATICAL BIOLOGY

Mathematical biology involves the construction of mathematical models to answer biological questions. To take a simple example, say that we know a crocodile increases in length by x cm every year (they continue growing throughout their lives, after all). How do we predict how long it will be in several years' time? This involves constructing a formula, in this case l = xy, where l is length and y is the number of years since it was born.

This formula is a very simple model of linear dynamics. If you drew it on a graph of length against time, it would be a straight line. Most biological processes are far more complex than that, especially when it comes to patterns in nature. Bard specialises in non-linear dynamics. "Non-linear dynamics are much more complicated because there are many possible states and paths, depending on where you start," he says. On the crocodile example, he expands, "As the crocodile grows in length, his girth also grows and, in fact, grows in a way that is proportional to his length; if his length doubles, his girth doubles. On the other hand, his weight will increase non-linearly, basically like his length cubed (since volume is proportional to length^3)."

DETECTING A PATTERN

Nature is full of patterns. Bard is interested in patterns that vary over space (such as spots or stripes) or time (such as rhythm). When we think of patterns, we most naturally think of spatial patterns, of which there are plenty of examples in the animal kingdom. Patterns that mimic an animal's surroundings, such as a tiger's stripes, help with camouflage, while patterns that stand out often act as a warning of danger. Recognition of these patterns can be deeply encoded within DNA. For instance, some birds will instinctively be afraid of a colourful snake, even if they have never seen a snake before in their life.

Temporal patterns are those that play out over time. For instance, think of a horse. When it is walking slowly, it moves one leg at a time; when trotting it moves diagonally opposite legs at once; and at a gallop, only one hoof touches the ground at a time. These are temporal patterns. "Gaits must be able to deal with uneven surfaces and obstacles, and using set patterns helps to overcome these," says Bard. We have our very own temporal patterns for walking, running, cycling, rowing and any other repetitive activity that our bodies undertake.

MATHS ON (AND IN) THE BRAIN

Bard takes a special interest in applying his expertise to neuroscience. "Many neuroscientists are interested in mechanisms, perhaps more so than most other biologists," he says. "We have new experimental methods that allow us to tackle problems that would have been unimaginable before. And, of course, the brain and nervous system are just very cool."

The human nervous system can be affected by patterns in odd ways. "When looking at a flashing light (a temporal pattern), some people can experience migraines or even seizures," says Bard. "In most, we will see geometric patterns called flicker phosphenes." Optical illusions provide another example: for instance, we might see flashing dots in high-contrast patterns, when no dots are actually there. Building models of why these effects happen is one of Bard's areas of interest.

THE MAKINGS OF A MATHEMATICIAN

"My aim is to provide explanations or mechanisms for things we observe in the natural world," says Bard. Being able to do this requires a comprehensive knowledge of modelling, and also the tools to put these into practice. "You need to choose the right tool, and the tools available are always expanding," he says. Models involve a simplification of a complex, messy system, and making sure that you simplify in the right direction is crucial. As Einstein said, "A model should be as simple as it can be but no simpler." Collaboration is also vitally important. Biologists tend not to have an in-depth knowledge of mathematics, and vice versa. Combining unique sets of skills is a cornerstone of good science.

HOW TO BECOME A MATHEMATICAL BIOLOGIST

- There are some undergraduate degrees available in mathematical biology, but more common degrees such as mathematics and, sometimes, biology can also lead to a career in this area.
- According to The Complete University Guide, the top UK universities for mathematics are Oxford, Cambridge, St Andrews, Durham and Imperial College London.
- According to Top Universities, the top US universities for mathematics are MIT, Harvard, Stanford, California Berkeley and Princeton. Bard advises that the best universities for mathematical biology are less well-known and include Utah, Michigan, Columbia and New York University.

PATHWAY FROM SCHOOL TO MATHEMATICAL BIOLOGIST

At school, mathematics, further mathematics, biology and other sciences are advantageous. At university, Bard recommends taking classes in calculus and linear algebra, and, if possible, basic science, probability and statistics, and differential equations.

Programming and coding ability will also prove useful. Bard advises learning LaTeX, the digital tool used for writing mathematical formulae and models, as well as some sort of higher-level programming language like MatLab or Python.

HOW DID DR BARD ERMENTROUT BECOME A MATHEMATICAL BIOLOGIST?

WHAT WERE YOUR INTERESTS AS A CHILD?

From an early age, I was very interested in science and knew I wanted to be a scientist. I collected insects and performed lots of chemistry experiments. I would make cultures of different bacteria and then use my microscope and staining techniques to try to identify them. I was very good at maths in high school and considered becoming a doctor before I settled on science.

WHAT INSPIRED YOUR CAREER?

At university, I began studying chemistry but quickly switched to pure maths after an advanced chemistry class introduced me to group theory. In my last year, I switched gears completely, when my attention was grabbed by a class on maths applied to biology. My interest was sparked further by a book on theoretical biology that covered catastrophe theory and neural networks. This led me to apply to the Department of Theoretical Biology at the University of Chicago. There, I was able to pursue my interests in applications of maths to neuroscience.

WHAT HAVE BEEN YOUR PROUDEST ACHIEVEMENTS SO FAR?

I co-developed the theory of weakly coupled oscillators, which I continue to build upon. I also built a software platform for modelling differential equations that is used by students and researchers around the world. I am also proud of the many successful students whom I have mentored over three decades of teaching.

HOW DO YOU 'SWITCH OFF' FROM YOUR ACADEMIC WORK?

I am an avid cook. My wife and I have a very well-equipped kitchen and make almost all our meals from scratch. I make fruit ciders and have learned to make a lot of different cocktails. I also have a big vegetable garden. I start all my plants in the late winter from seed and then fight off deer, drought and fungus during the summer!

WHAT ARE YOUR FUTURE AMBITIONS?

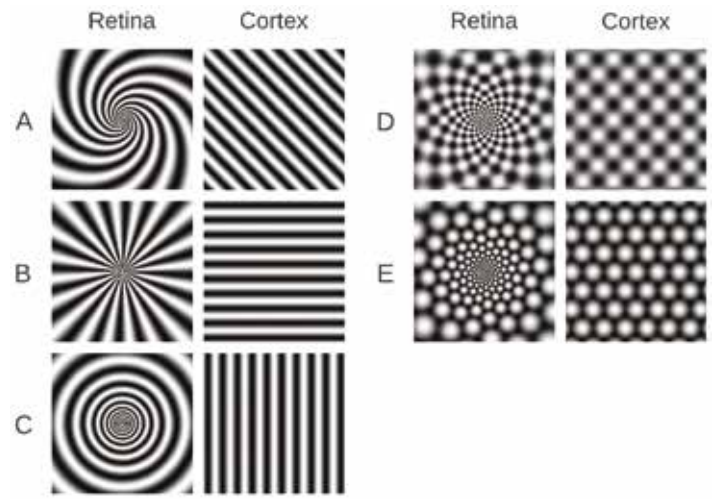
I would like to uncover more about the reasons for the patterns we observe. For instance, why are there so many waves and oscillations happening in the brain? How do they relate to higher brain function?

BARD'S TOP TIPS FOR STUDENTS

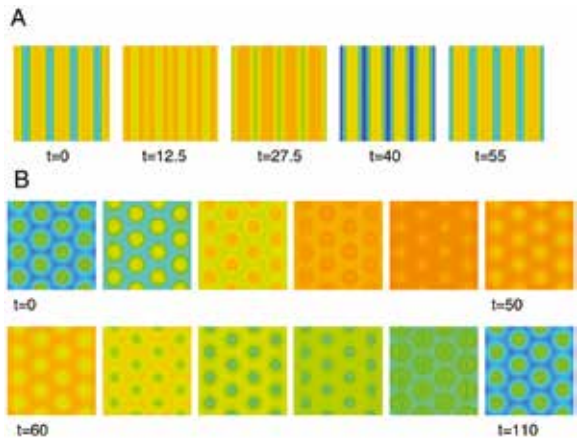
1 Find something that truly excites you and follow it.

2 Learn how to communicate with other scientists, especially those who might not know much mathematics.

3 Find some good mentors and, if you can, work on projects alongside them.



Cortical patterns (second column) such as produced in the color figure are perceived not as stripes but as spirals, bullseyes or spokes (retinal column). Hexagons and checkerboards look like sunflower heads. This is due to the way information in the eyeball (retina) is wired onto the brain (cortex).



(A) Response to a model neural network to high frequency (20 cycles/sec) stimulus causes stripes to appear.

(B) Response to low frequency (10 CPS) stimulus produces hexagons.

MATHEMATICS: PLANE AND SIMPLE

DR SAM BALLAS IS BASED AT **FLORIDA STATE UNIVERSITY** IN THE US. HIS RESEARCH FOCUS IS ON GEOMETRY AND SURFACES, WHICH IS A BRANCH OF MATHEMATICS. SAM'S PASSION FOR THE SUBJECT SHOWS THAT ALTHOUGH MATHS CAN BE CHALLENGING, IT CAN ALSO BE EXTREMELY REWARDING

TALK LIKE A MATHEMATICIAN

TOPOLOGY
The study of geometrical properties and spatial relations that are unaffected by changes to the shape or size of figures. To a topologist, a coffee cup and a doughnut are the same shape, since one can be deformed to the other without tearing!

CONVEX
A shape is convex if any two points can be connected by a straight line that is contained in the shape.

PROJECTIVE GEOMETRY
A topic in mathematics that studies geometric properties that are invariant with respect to projective transformations. An example is a film projector projecting a movie onto a screen. This is also how our vision works, where objects at different distances are projected onto our 'visual sphere'. This is why when you look down a set of railway tracks, they look like they start to get close together.

MANIFOLD
A topological space that 'locally' resembles Euclidean space. A manifold is a higher dimensional analogue of a surface in two dimensions or a circle in one dimension.

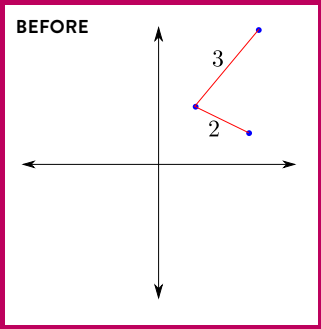
PLANE
A flat, two-dimensional surface that extends infinitely far.

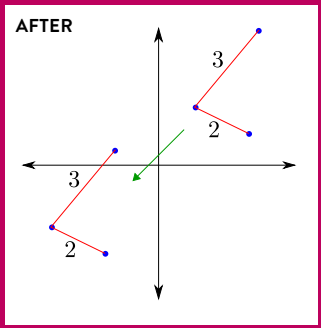
TRANSLATION
A geometric transformation that moves every point of a figure or a space by the same distance in a given direction.

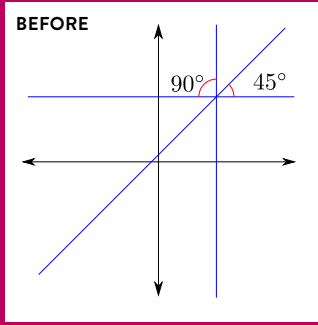
ROTATION
A motion of a certain space that preserves at least one point.

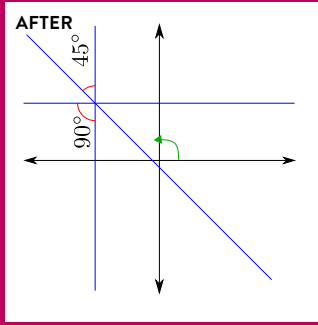
GENUS
A topologically invariant property of a surface defined as the largest number of nonintersecting simple closed curves that can be drawn on the surface without separating it. Intuitively, this is the number of holes in a surface.

TORUS
A two-dimensional shape made by revolving a small circle along a line made by a bigger circle – it often looks like a doughnut or rubber ring. We usually view it in three-dimensional space, but it is really just the 'skin' of the doughnut, which has no thickness.









SAM'S TOP TIPS

1 I really cannot overstate how important I think it is to find something you are interested in and passionate about – that will make it so much easier to overcome any obstacles you might face in your studies because you will really care about what you are doing.

2 It is easy to say from a vantage point of being older, but I highly recommend that when you are young, you should try to learn about as many different things as possible. You never know where your passion might lie and by widening your field of enquiry, you will increase your chances of finding what is right for you.

3 Becoming a mathematician often involves a lot of computing, so I recommend trying to learn to programme in at least one programming language, such as Python. In the current world, programming is an indispensable skill for pretty much any STEM-based career.

DR SAM BALLAS

Department of Mathematics, Florida State University, USA

FIELD OF RESEARCH

Mathematics

RESEARCH

Sam's research is concerned with a wide range of mathematical problems. One of his main interests in the hyperbolic plane, which can be particularly useful for modelling chaotic behaviour, where small changes in initial conditions can cause large changes in overall behaviour.

FUNDER

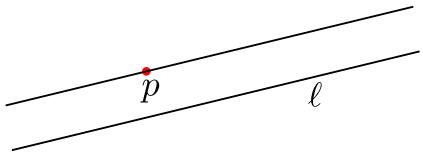
National Science Foundation

Geometry is a branch of mathematics that is concerned with the size, shape, positions, angles and dimensions of things. We are all familiar with geometric shapes in two dimensions, such as a square, circle, triangle and rectangle, and three dimensions, such as a cube, triangular prism, square-based pyramid and cuboid. However, while those examples are clear and easy to follow, there are mathematicians that are engaged with geometrical problems so complex that explaining them in ways that are easy to understand is extremely difficult. For example, though we view a sphere in a three-dimensional space, it is like a torus and is actually a two-dimensional shape! Indeed, understanding many geometric problems is much easier if you can visualise what is being described rather than merely reading words.

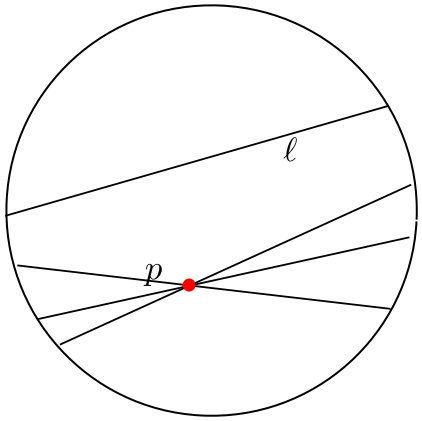
Dr Sam Ballas, who is based at Florida State University in the US, is a mathematician who is focused on geometry of surfaces and their higher dimensional cousins, manifolds. "My interest in geometry stems from my always trying to understand things visually and I am always trying to draw pictures of things to help me better understand them," says Sam. "I also like to think about how different objects can be stretched and deformed to one another. For me, this type of approach has always been helpful in studying geometric problems."

WHAT ARE THE MAIN TOPICS OF SAM'S RESEARCH?

Sam is involved in several related projects, but one of his main topics of enquiry is the geometry and topology of convex projective manifolds. His work focuses on something known as the hyperbolic plane, which can be thought of as the exotic cousin of the standard plane, and both share many properties. "Both of these planes have a notion of straight lines and angles, and you can do a lot of things in the hyperbolic plane that you can do in the regular plane, such as connect any two points with a straight line," explains Sam. "The main difference is that there are a lot more parallel lines in the hyperbolic plane."



The Euclidean parallel: for each point (p) and each line (l) through that point, there is a single parallel line.



The hyperbolic parallel: there are many parallel lines to the line (l) through the point (p).

In the regular plane, if you have a line and pick a point not on that line, there is only one line parallel to your line through that point. However, on the hyperbolic plane, there are infinitely many more lines through your point and parallel to your line. Knowing this has many important consequences, such as the fact that many nearby straight lines 'spread out' very quickly – this makes them useful for modelling chaotic behaviour, where small changes in initial conditions cause large changes in overall behaviour.

WHAT ARE THE MAIN HIGHLIGHTS OF SAM'S WORK?

One of Sam's favourite results so far is showing that certain three-dimensional objects can be glued together to form more interesting objects. "The thing I liked most about this result is that it generalised a nice and well-known two-dimensional picture of gluing together surfaces, but was previously unknown in the third dimension," says Sam. "This analogy was very helpful for me and my collaborators when we were trying to prove the result because we could fall back to the more familiar two-dimensional setting for inspiration."

DOES SAM'S WORK HAVE ANY 'REAL LIFE' APPLICATIONS?

Yes! One of the applications of Sam's work is that certain geometric objects can be used to produce what are called expander graphs. Informally, a graph is just a collection of dots (called vertices) where some of the dots are connected to each other by lines (called edges). You can think of graphs as physical objects, but you can also think of them as network connection between two computers," says Sam. "Roughly speaking, an expander graph is one that has many more vertices than edges but is still very hard to disconnect by removing a small number of edges."

Such a graph could be useful for building a robust computer network, as it would require relatively few connections, but the link between two computers cannot be broken without many connections being severed.

ABOUT MATHEMATICS

The history of mathematics is long and varied. From the notched bones in prehistoric Africa (which provide evidence of our thinking about numbers), the Moscow Papyrus (the oldest mathematical text from ancient Egypt), through to Isaac Newton's use of calculus in the laws of motion and gravitation, maths has provided mankind with a means of understanding the world (and universe) around us.

One of the main attractions of maths is that its work is never done; every century since the Renaissance has seen more mathematical problems solved than the century before, yet many problems remain unsolved. In 2000, the Clay Mathematics Institute posited seven Millennium Prize Problems which were thought to be some of the most difficult problems mathematicians were grappling with. Since then, only one – the Poincaré Conjecture – has been solved, with Dr Grigoriy Perelman claiming the honours and being awarded $1 million (which he rejected on account of his believing his contribution to the solution was no greater than that of Richard S. Hamilton's).

Perhaps you could be the one to solve one of the remaining six problems and cement your name in history...

WHAT ARE SOME OF THE KEY QUESTIONS THAT TODAY'S MATHEMATICIANS ARE TRYING TO ANSWER?

When we spoke to Sam about his work and the broader scope of enquiry within the field of mathematics, he actually referenced a couple of the aforementioned Millennium Prize Problems. "One of the most interesting problems is the Riemann Hypothesis, which is concerned with the distribution of the prime numbers amongst the integers," says Sam. "Then there is the P vs NP Problem, which is about quantifying how much harder solving a problem can be than checking that a proposed solution is correct." One of the clearest examples of this is to think about Sudoku problems – how much harder is it to solve a Sudoku puzzle than verify that one has been completed correctly? Only maths can provide an answer, yet the problem remains unsolved.

ARE THERE ANY OPPORTUNITIES TO COLLABORATE WITH OTHER MATHEMATICIANS?

Mathematicians have collaborated multiple times over the centuries. The old adage, two heads are better than one, certainly applies in the field of maths, although it can often be a solitary pursuit and many mathematicians work on their own volition. Still, Sam is positive about the collaborative environment within maths. "Most of the time, mathematicians are people who are good at taking a problem, stripping away the unimportant extraneous details and revealing the real essence of the problem," says Sam. "This often makes them able to help make progress on problems where they initially do not have a ton of domain specific knowledge. For instance, I know several mathematicians at Florida State (and elsewhere) who have helped solve important problems in biology, geology, and pharmaceuticals."

WHAT MAKES A GOOD MATHEMATICIAN?

Sam believes that two attributes in particular make a good mathematician – curiosity and resilience. "For curiosity, I really mean the mindset of always looking for ways in which different things are connected and similar to one another," explains Sam. "As for resilience, one of the most consistent features of doing almost any kind of research is failure. Most of the things you try are not going to work and it is important to be able to keep going and not be overly discouraged by repeated failure. I would say in my work that I am failing about 90% of the time, but I find the 10% of time I am successful is so rewarding that it helps me push through the other 90%."

THE FIELDS MEDAL

The most prestigious of mathematics prizes, the Fields Medal is awarded to two to four mathematicians every four years at the International Congress of the International Mathematical Union (IMU).

WINNERS INCLUDE:

- Grigory Perelman was offered but, again, declined the medal.
- William Thurston is described as 'pioneer' in the field of low-dimensional topology. Awarded the medal for his work on manifolds, Thurston has been very influential on Sam's work.[1]
- Maryam Mirzakhani, one of the most famous researchers in Sam's field, was the first woman to win the Fields Medal, awarded to her for her work on "the dynamics and geometry of Riemann surfaces and their moduli spaces". Unfortunately, she died recently and at only 40 years old, but her story is inspirational and worthy of further reading.[2]

[1] *https://en.wikipedia.org/wiki/William_Thurston*
[2] *https://en.wikipedia.org/wiki/Maryam_Mirzakhani*

HOW DID DR SAM BALLAS BECOME A MATHEMATICIAN?

WHAT WERE YOUR INTERESTS AS A CHILD? DID YOU ALWAYS KNOW YOU WANTED TO BE A MATHEMATICIAN?

Being a mathematician was definitely not on my radar when I was a kid! My father is a physician and growing up, I always envisioned myself going into medicine. I didn't really get into maths until I was at university and had the opportunity to take more interesting and advanced maths classes. This was the first time I got to see that maths was a lot more than the rote computations and formulas that I had been previously exposed to.

WHO HAS INSPIRED YOU IN YOUR CAREER?

I have had the pleasure of being able to learn from and be mentored by a lot of amazing people throughout my career. If I listed everyone who has inspired me, it would be an extremely long list, but a few who stand out are Emily Hamilton, Frank Pajares, Alan Reid, Ted Odell, Daryl Cooper and Darren Long.

HOW DO YOU OVERCOME OBSTACLES IN YOUR WORK?

I think resilience is key to overcoming challenges in my work. It is important to develop a feel for when you are making progress but haven't quite made it to the end, and when you are truly stuck. Of course, this is easier said than done and is often only obvious in retrospect. It is also good to have a few different things to work on at any given time – that way you can turn your attention to something else if you are stuck on a project. There have definitely been times where I have felt stuck, gone to work on something else, and then come back to my original problem with fresh eyes and was able to make progress.

HOW DO YOU 'SWITCH OFF' FROM YOUR ACADEMIC WORK?

This can be a real challenge at times. When I have a problem I am really interested in it's usually the last thing I think about at night and the first thing I think of when I wake up (sometimes even in the middle of the night!). Something that has helped in recent years is becoming a dad. Being a parent requires a lot of your focus and when my son, Eli, wants to play with me, he is not typically very sympathetic if I tell him that "Dada is thinking about a math problem right now!" If you don't think that having a child for the purpose of switching off from your academic work is a good strategy for you, then you can also try exercising – I have also had some success with that!

HAVE YOU SET YOURSELF ANY GOALS YOU WOULD LIKE TO REACH IN THE FUTURE?

In a broad sense, I would like to continue to study and make progress on problems that I find interesting. I would also like to become more involved in graduate education and outreach activities – to this end, one of my more tangible goals is to establish an experimental mathematics lab at Florida State where students can work in small groups on projects that focus on math as an experimental science. The idea is that students will form hypotheses and design and implement experiments to test them.

HOW TO BECOME A MATHEMATICIAN

• The Math Learning Center (https://www.mathlearningcenter.org) has a host of resources for all levels of ability. Their resources include free math apps covering a wide range of topics, including a Geoboard.

• The Millennium Mathematics Project (https://maths.org/) is a maths education and outreach initiative for ages 3 to 19. It aims to enrich everyone's experience of mathematics and increase their understanding, confidence and enjoyment.

• The average salary for a mathematician in the United States is $101,900. Wages typically start from $57,150 and go up to $160,550. (https://www.careerexplorer.com/careers/mathematician/salary/)

PATHWAY FROM SCHOOL TO MATHEMATICIAN

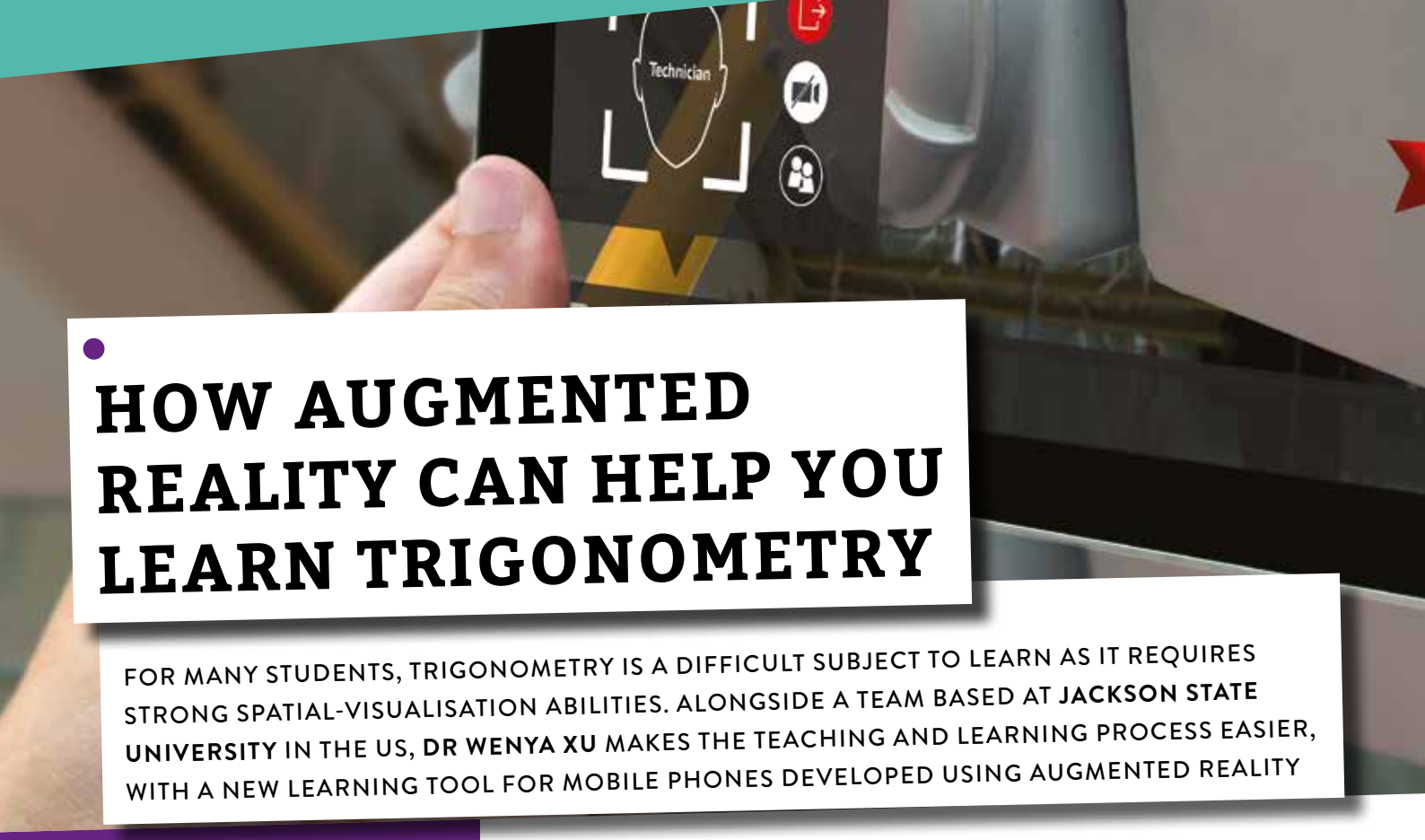
Sam believes that two classes that are helpful to pretty much any mathematician are calculus and linear algebra. These subjects are particularly useful if you are interested in learning about machine learning and data science, although the benefits of calculus and linear algebra are generally far-reaching.

2 or 3 A levels, or equivalent, including maths

A degree in mathematics, physics or applied mathematics

https://www.careerexplorer.com/careers/mathematician/education/

Sam at FSU's 'Math Fun Day'



HOW AUGMENTED REALITY CAN HELP YOU LEARN TRIGONOMETRY

FOR MANY STUDENTS, TRIGONOMETRY IS A DIFFICULT SUBJECT TO LEARN AS IT REQUIRES STRONG SPATIAL-VISUALISATION ABILITIES. ALONGSIDE A TEAM BASED AT **JACKSON STATE UNIVERSITY** IN THE US, **DR WENYA XU** MAKES THE TEACHING AND LEARNING PROCESS EASIER, WITH A NEW LEARNING TOOL FOR MOBILE PHONES DEVELOPED USING AUGMENTED REALITY

TALK LIKE AN EDUCATOR USING AUGMENTED REALITY

Augmented reality (AR): Visualisations of the real world enhanced with computer-generated elements, usually displayed on a smartphone or tablet. This is not the same as virtual reality (VR), where the real-world is completely shut off (think of VR goggles).

Trigonometry: A mathematical subject studying the relationships between side lengths and angles of triangles.

Spatial visualisation: How we visualise two-dimensional and three-dimensional objects in our minds without seeing them directly in front of us. When looking at a 2D map, we are using our spatial-visual abilities to mentally understand it in 3D.

Interface: Defined as a connection between a person and a computer. An app being used by a person on their smartphone, tablet or computer can be called an interface.

Beta testers: People using an app to test it out before it is released publicly. Any errors reported by the beta testers are sent back to the app development team to solve.

Imagine you are in a trigonometry lesson, but instead of looking at the teacher's whiteboard, you have a mobile device in your hand. You hold the device in front of you to detect a flat surface. You tap the screen and the app you are using generates two objects – one is a Star Wars' Republican Guard and the other is a tower! No, you are not distracted from your learning. You are using augmented reality technology called Plane Detection and you are about to combine it with your trigonometry knowledge to calculate the height of the tower.

Trigonometry is a daunting subject for many students, but this does not need to be the case. Scientists think that the ability to do well at this mathematics subject relates to our spatial visualisation abilities – imagining a 3D concept can be difficult when we are looking at a diagram in 2D.

To help students visualise and learn trigonometry, research assistant Wenya Xu and a team at Jackson State University created a new learning approach using augmented reality (AR). After producing an AR app for mobile phones, they tested it out on freshman (in the UK, year 10) students, to see if it helped, and found promising results.

HOW CAN AR HELP US LEARN MATHEMATICS?

All students have their own learning needs, so teachers face challenges when using one learning method for everyone in the maths classroom. Studies have shown that spatial visualisation is important when problem-solving, visualising abstract ideas and learning STEM subjects.

Wenya explains, "Spatial visualisation is a crucial ability to understand and solve STEM-related problems. Some students may struggle to understand 3D concepts represented in a traditional classroom setting where concepts are presented in a 2D manner. STEM teaching and learning could benefit from a new approach which aims at enhancing students' visual-spatial ability."

Imagine you are back in that maths lesson with the AR app but, this time, you are looking at a unit circle. You are using a virtual red stick to connect the circle centre and the circle rim. You can rotate the stick clockwise or anticlockwise to different degrees. The device records the data as you move the stick and you can see the maths 'in front' of you. This can help both your teacher to teach and you to learn because, as Wenya explains, "AR offers an efficient way for teachers to use hands-on approaches through the interaction and manipulation of trigonometry models."

HOW DID THE RESEARCH TEAM CREATE AND TEST THE AR LEARNING TOOL?

Wenya's team designed their AR app to be used on an Apple iOs device, since students find it easy to use. It goes without saying that students are accustomed to using mobile

devices – how they would get on with the AR learning tool was the all-important question.

To get accurate results, the researchers had to compare a class using the AR interface to one not using it at all. This is similar to what medical studies do in clinical trials where there is an 'experimental' and 'control' group. The first has the subject being tested on them (such as a new drug) and the second has no new subject (such as a placebo, causing no new effects).

Wenya's research team applied this experimental approach to the maths classroom, where a teacher took two class sessions – one was the experimental and the other was the control group. For the first group, the AR interface was used by the students to learn, but in the control group, the teacher used the traditional whiteboard method. To find out how well the students performed, both classes took four exams during the semester (the school term). The experimental group also filled out a survey about their attitudes towards trigonometry after using AR, reporting how useful and enjoyable they found it.

THE BIG QUESTION: DID AR HELP THE STUDENTS LEARN TRIGONOMETRY?

The exam results showed that the class who used AR (the experimental group) scored higher grades than the control group who did not use the interface. When we look at how the exam results varied throughout the semester, we can see that the experimental group scored notably higher on the first exam compared to the control group. After that, the difference in the exam results between the two groups was less significant.

The research team thinks this could be because the AR style was new and appealing to students at the start of the project – making them more interested and engaged in trigonometry, scoring higher as a result.

Wenya concluded, "This research has provided evidence of the potential learning benefits of AR technology in trigonometry teaching and learning." She adds that the study, "discovered the positive impacts of an AR trigonometry interface on students' achievements at the early stage of learning, which indicated that AR has a good potential to improve students' learning outcomes in trigonometry."

Overall, results showed that AR helped the students achieve higher grades and most students found it a better way to learn trigonometry. This shows the potential benefits of applying AR technology in education, to not only make the experience more enjoyable, but to facilitate higher grades.

You don't need to love mathematics to be involved in AR for education, as it can be used to support many different subjects. If you are looking for a career in education, introducing interactive tools such as AR could help you open new doors of learning for students. Wenya has already achieved this at the early stage of her research career.

DR WENYA XU

Research Assistant
Jackson State University, USA

FIELD OF RESEARCH

Education

RESEARCH

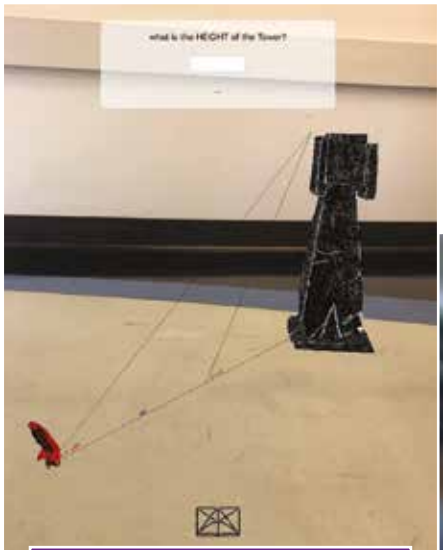
Creating an augmented reality interface to raise student attainment in trigonometry.

FUNDER

National Science Foundation

Wenya was the first author of the scientific report for this project. She worked with the following people, all based at Jackson State University:

Farshad Amini
Lin Li
Chao Jiang
William Brown
Jianjun Yin



Trigonometry application example.

ABOUT AUGMENTED REALITY FOR EDUCATION

As we have seen, AR can make learning trigonometry more interactive and enjoyable. Yet, it is a tool that can support students in subjects beyond mathematics.

You don't even need to be in the classroom, as AR can also help you learn new skills on your smartphone. There are AR astronomy smartphone apps where you can learn where constellations are in the night sky. The interface adds text and images to your view of the sky above, making it easier to remember where the constellations are. Or you can broaden your navigation skills using Google Maps, which now adds arrows to your view of the real world to direct you.

HOW USEFUL IS AR FOR LEARNING DIFFERENT DISCIPLINES?

When used the right way, all age groups can use AR to learn. Wenya explains, "AR could benefit all age group learners, including early childhood students, if used in an appropriate and effective way."

This approach can be applied to more than just STEM, but arts subjects, encompassing history, English, architecture and design.

AR can help us visualise objects we cannot normally see at the tiny (micro) or huge (macro) level, like seeing how atoms move, or how continents collide across hundreds of kilometres. Having help to comprehend new ideas makes them more memorable and interesting.

AR can help teachers illustrate their lessons across a broad range of subjects, making their lessons more interactive. "The integration of AR into classrooms allows teachers to use hands-on approaches through interaction and manipulation of models," Wenya says. Looking to the future, AR could become a vital part of distance learning, especially as remote learning has become increasingly common during the coronavirus pandemic. Teachers are already using it during live video lessons to keep their students engaged.

WHAT IS IT LIKE TO DEVELOP AN AR APP FOR EDUCATION?

Developing an AR interface requires team-effort and skills in computing and design. Designers plan how the app should look and feel, while computer programmers build it to be used on our phones, tablets or computers.

Once a working model is made, the team can test it out by using beta testers, who send any problems back to the team to solve. To save time, there are also some software packages that allow you to build AR apps, like Unity and Buforia. This way, computer programmers may not be needed, but you will need to learn how to use these packages with the help of online guides and video tutorials.

It can be a rewarding experience for educators using AR to help students achieve higher grades. Wenya was pleased to see a rise in student attainment in trigonometry after introducing AR.

There is clearly potential for AR to help students learn, but there can be some challenges, as each AR system has to be designed for different skills, levels and age groups. Testing these systems also takes time, usually with a low number of participants at first. Ideally, it is best to have as many participants as possible, so that test results can be supported with more data.

HOW TO BECOME AN EDUCATIONAL RESEARCHER

- Obtain a bachelor's degree relevant to education in STEM or the arts.
- Jackson State University offers the Unite Pre-Engineering Summer Program for high school students from historically underrepresented and underserved groups in STEM.
- According to Indeed, a research assistant averages a salary of $36,673 per year, but this varies depending on the subject of study.
- If you prefer to teach secondary/high school students, the average salary of a teacher is $49,548 per year, according to PayScale.
- For focusing on the development of AR apps, an AR designer could gain an annual salary of $75,720, according to Study.com.

PATHWAY FROM SCHOOL TO EDUCATION

You will require a bachelor's degree to work in education or to become a research assistant, but there is a broad range of subjects you could study – choose one that captures your interest the most. Wenya recommends mathematics, science, foreign languages, bilingual education, special education, or cultural studies and diversity.

If you would like to focus on developing augmented reality tools, you can apply to study augmented reality at university level. UW Reality Lab at University of Washington offers undergraduate and postgraduate courses in AR. In the UK, BSc Virtual and Augmented Reality courses are available at Bournemouth University, University of Bradford, University of Portsmouth, and Cardiff Metropolitan University. A new course, BA Augmented and Virtual Realities is offered by Staffordshire University.

HOW DID DR WENYA XU BECOME AN EDUCATIONAL RESEARCHER?

WHO OR WHAT HAS INSPIRED YOU IN YOUR CAREER?

My love for school and education has inspired me to develop my career. As a child, I was always very interested in reading and outdoor activities, which has helped me to remain open to learn about the world around me. Now, I am an early career researcher who has had the opportunity to test a new learning approach in the classroom using AR.

I served as a research assistant during my doctoral study at Jackson State University and graduated in 2019. Even though I am still starting out in my academic research career, I feel a sense of accomplishment that I have successfully introduced AR in the maths classroom. It will be exciting to see what innovations I will implement next during my research, and how the world of education will change in the coming years.

WHAT MAKES LEARNING ENGAGING FOR YOU?

The meaningful and informative learning process keeps me engaged. I enjoy reading the latest resources and learning new information.

WHAT ATTRIBUTES MAKE YOU A SUCCESSFUL RESEARCHER?

Personally, I feel I have an analytical, curious mind and a strong commitment to the research process. I will systematically work through problems and be open to learning during research projects.

HOW DO YOU OVERCOME OBSTACLES IN YOUR WORK?

I have two main approaches that have helped me to overcome obstacles:

1) Setting a clear and detailed schedule. This allows me to stay organised.

2) Making any obstacles I face the number one priority. Every day, I commit time and effort to solving a problem until it is gone. This requires patience and follow-through.

WENYA'S TOP TIPS FOR STUDENTS

1 Be open to learning continuously.

2 Have passion for life and feed your interests.

3 Learn from mistakes. If you get bad grades, have courage to keep going and try again.

4 Set a clear and detailed schedule.

WENYA'S TOP TIPS FOR TEACHERS

1 Keep a structured schedule and routine for children.

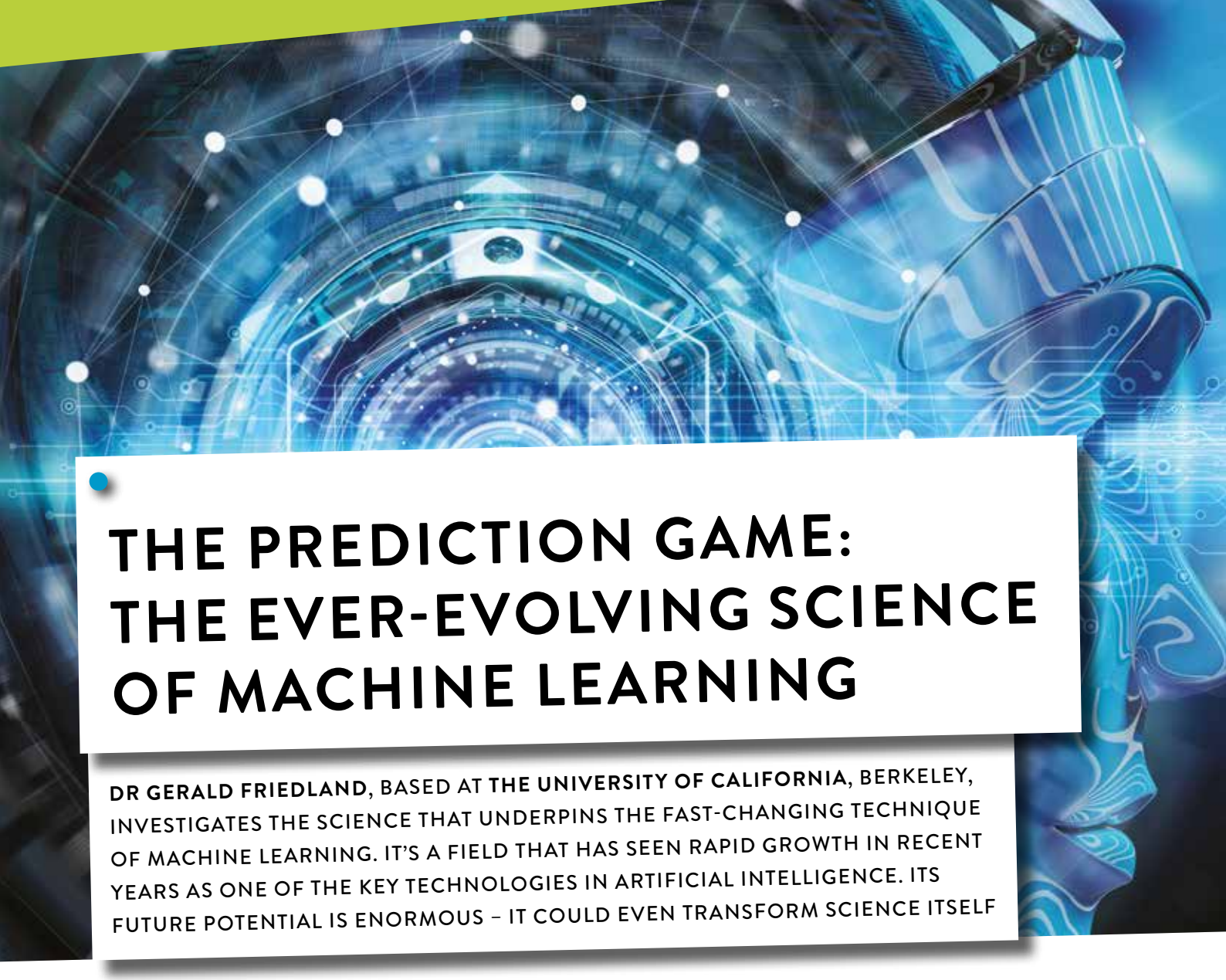
2 Aim for short, fun sessions and be prepared to be flexible.

3 Get creative and mix up methods for learning.

4 Be sure to interact with colleagues and parents.

Wenya's PhD graduation.

AR trigonometry Class ©2020 Wenya Xu. All rights reserved.



THE PREDICTION GAME: THE EVER-EVOLVING SCIENCE OF MACHINE LEARNING

DR GERALD FRIEDLAND, BASED AT **THE UNIVERSITY OF CALIFORNIA**, BERKELEY, INVESTIGATES THE SCIENCE THAT UNDERPINS THE FAST-CHANGING TECHNIQUE OF MACHINE LEARNING. IT'S A FIELD THAT HAS SEEN RAPID GROWTH IN RECENT YEARS AS ONE OF THE KEY TECHNOLOGIES IN ARTIFICIAL INTELLIGENCE. ITS FUTURE POTENTIAL IS ENORMOUS – IT COULD EVEN TRANSFORM SCIENCE ITSELF

When you speak into a device to ask for a weather forecast, a football score or a music track, Siri or Google or Alexa usually understand your words and try to provide the best answer. You may not even remember the first time you ever tried this. And at the time, you probably didn't think how amazing it was that a device could recognise your voice, even though it had never heard it before.

The computing method behind voice recognition, and many other applications, is called machine learning. It's one of the key technologies of artificial intelligence, which aims to give computers and robots the ability to perform tasks that previously only humans could do.

While machine learning has been improving in leaps and bounds in recent years, there's still vast potential for improvement. This is the focus of research activity by Dr Gerald Friedland, Adjunct Assistant Professor at University of California Berkeley and co-founder of a technology company called Brainome, Inc. According to Gerald, the technology could even change the way scientists work.

WHAT IS THE SCIENCE BEHIND MACHINE LEARNING?

Machine learning is a computing method that is used to infer a function, often called a model, from observations. As an example, you could make observations of various aspects of used cars, such as the manufacturer, model, age, size and condition. You could also list the price that each car was sold for. Do this for a lot of cars and you'll have collected a big set of data.

You could then 'train' a computer to create a model of used car sales based on the previous sales figures. This is machine learning. Given various bits of information about a car, the model could be used to predict that, for example, a 2018 Ford Fiesta that was in good condition would sell for £8,350. It would only be a prediction, of course, and many factors determine how accurate the prediction would be. To date, machine learning has been dominated by statistics, a branch of mathematics. Maths is a very powerful tool used by scientists to describe things precisely.

HOW DOES MACHINE LEARNING WORK?

When experiments are performed, a table records all the factors that go into it in one row. There's another set of rows for the observations. As we vary the experiment and do it again, a new row is created each time.

Remember Isaac Newton? He is said to have discovered gravity when an apple fell on his head. And not only that, he also created a model of how energy is related to gravity. It's fun to imagine him dropping the apple on his head from different heights and noting how much more painful it was when dropped from higher up! (He didn't actually do this, so don't try it at home!)

The result of this imaginary experiment would be a table where the first column records height and the second column records the 'pain level'. Newton trained his brain on this table to figure out that energy (pain) is proportional to height.

In machine learning, the first step in this process, creating a table, is memorisation. The

DR GERALD FRIEDLAND

Adjunct Assistant Professor at University of California Berkeley and CTO of Brainome, Inc.

FIELD OF RESEARCH

Computer Science

RESEARCH PROJECT

Using science and engineering methods to improve the design of neural networks

second step - creating a formula (a model) to describe the table and all experimental outcomes of the same setup in the future - is called generalisation.

In computer science, we want a machine learning model to create the formula and be able to predict future experiments. In other words, we want machine learning to generalise.

WHAT ARE THE CHALLENGES THAT NEED TO BE OVERCOME?

Often, all a machine learner does is memorise the table of observations as it is not (yet) able to generalise. This is called 'overfitting' and it's one of the most recognised problems in machine learning. However, it is often misunderstood. When the experimental set-up presented to the machine learner in training is too complex for the amount of training data, then all the machine learner can do is overfit – this is memorising. Memorisation is the first step. But it's a worst-case scenario when it comes to generalisation. Such a model would not be able to make future predictions and would therefore be useless.

WHAT HAVE BEEN THE OUTCOMES OF GERALD'S RESEARCH?

Gerald has been working on measurements for the design and training of neural networks. These mimic the way animals' (including humans') brains work. He treats each neuron (brain cell) like an electrical element in a circuit. By doing this, he can come up with rules similar to Ohm's law that describe how neurons behave when they are combined, just like resistors in a circuit. While the units of an electrical circuit are Volt, Ampere, and Ohm, the units in an information network are bits. All of these units can be translated back into physical measurements. One result is the ability to solve problems using neural networks that are much smaller than it's been possible to use so far. Gerald is currently working on building a speech recogniser with a dozen neurons.

Ultimately, Gerald's research involves applying physics to the world of information. He wants to make machine learning as easy as possible. His ultimate goal is to make it 'plug and play' so that it's as simple to use as selecting rows and columns in a Microsoft Excel spreadsheet and pressing a button.

HOW WILL MACHINE LEARNING BE APPLIED IN THE FUTURE?

Machine learning will become easier to use, and used in even more AI applications in the future. But Gerald has an even more futuristic vision. He thinks that machine learning will be able to replace part of the job previously done by scientists. Great thinkers of the past, like Einstein, came up with equations as a result of a process inside their brains. Einstein generalised a table of observations to come up with his famous formula E=mc2. He did it inside his head, and on paper. But in future, the deduction of scientific formulae will be done by computer. As a result, scientists won't need to come up with formulae. Instead, they will have the job of posing the right questions and collecting the data in a clean way. They will also be needed to explain the results produced by the machine to a broader audience.

ABOUT MACHINE LEARNING

The applications of machine learning have mushroomed in recent years. Anywhere that data is collected, machine learning can be employed to predict future behaviour.

When you buy from an online store, data is stored of how you found the website, and which products you clicked on. The patterns of behaviour can then be used to identify similar people and send them targeted adverts.

Similarly, machine learning predicts the TV shows you'll want to see on Netflix, and whose posts you'll be interested in seeing on Facebook and other social media platforms. Machine learning is also at work in identifying fraudulent activity on your bank account and in satellite navigation.

WHAT DOES THE FUTURE HOLD FOR MACHINE LEARNING?

The future of machine learning will be even more exciting than the present. It will be the technology behind driverless cars, augmented reality, and improved voice recognition and computer interfaces. It will make computer vision an everyday reality, allowing robots to move freely, and safely, around because they will be able to understand what they are seeing through their cameras. And augmented reality, which will overlay what we see through smart glasses or on our phone screens, will understand which information to give us – and when. If you see a friend on the street, augmented reality will remind you if it's their birthday.

WHAT SHOULD I STUDY TO GET INTO MACHINE LEARNING?

Machine learning is a branch of computer science, but future advances will take it out of the world of mathematics and statistics and into the real world. That's why it's a good idea to study physics at school, while you also learn how to programme computers and participate in open-source projects. For example, you can experiment with simple hardware such as Arduino and learn the basics of the Unix command-line user interface, using Linux, for example. When you get to college, relevant subjects include linear algebra, statistics, and information theory. You should also take classes in statistical mechanics and thermodynamics, and computer architecture.

WHAT OTHER QUALITIES ARE USEFUL?

According to Gerald, to be a success in the field of machine learning, it's important not to skip the fundamentals. It's not worth getting too hooked on any particular technology to the exclusion of others. That's because in computing, programming languages, tools and methodologies go in and out of fashion. If you know the fundamentals, you can adapt to the tools that are currently trendy, see the world for what it is, and be an innovator in a fast-changing world.

OPPORTUNITIES IN MACHINE LEARNING ENGINEERING

According to the careers website Prospects.ac.uk, machine learning is such a new field that there are few academic courses dedicated to it.

Instead, most employers accept a Masters degree or a PhD in a relevant subject. If you want to follow this as a career path, the best advice is to study a subject that has an element of machine learning within it.

Computer programming experience is essential, and employers look for knowledge of programming languages, including C++, Java, and Python.

If you don't have a degree, you could still get into the field if you have experience in data or statistical analysis and take a dedicated Udacity course.

The average UK salary for a machine learning engineer is £52,000, but you could be paid much more if you join a large multinational company.

GERALD'S TOP TIPS

1. Read Feynman Lectures On Computation by the Nobel prize-winning physicist Richard Feynman.
2. Take the time to actually understand things by asking and looking for answers to the 'why?' question. An answer is valid if, and only if, it fits many viewpoints.
3. It's OK to be a nerd! I got an F in art on my 12th-grade report sheet!

HOW DID DR GERALD FRIEDLAND BECOME A MACHINE LEARNING ENGINEER?

DID YOU ALWAYS WANT TO WORK WITH COMPUTERS?

Yes, absolutely – I started programming at the age of 7 years old and machine learning when I went to university as an undergraduate. I did consider physics for a while too. I've written a book for elementary school children called, 'Beginning Programming Using Retro Computing', because I love the idea of young people working with computers as early as I did!

WHO OR WHAT INSPIRES YOU?

I love to make things that work. I am also inspired by simplifying complicated things - I'm driven by explaining difficult things in a way that makes people say, "OMG, that makes sense! I never thought about it that way."

WHAT FASCINATES YOU MOST ABOUT COMPUTER SCIENCE?

Computer science is an engineering discipline that builds machines to automate maths. Less than a century ago, maths was the king discipline that governed all sciences. Now for the first time, computer science is able to show that maths itself is physical. We can build a mechanistic machine that solves mathematical problems. So, for the first time in history, we have a means to question maths and ask the 'why' questions. For example, I have a 10-minute lecture on YouTube that explains why prime numbers exist. Maths defines and observes prime numbers as a phenomenon. But computer science can explain *why* they have to exist - it's a result of multiplication being a compressed representation of addition. This then allows us to reason about their importance for encryption, for example.

WHAT ARE THE MOST PRESSING ISSUES FOR COMPUTER SCIENTISTS TODAY?

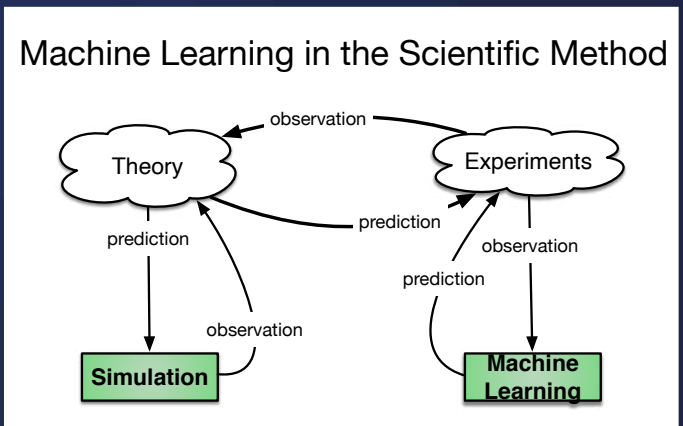
Programming and the fundamentals of information need to be taught in school so that there is time to actually teach the science of computer science in college. Because programming is taught so late, most computer scientists see themselves as programmers when they graduate from college. So, we miss the opportunity to see computer science as a rigorous science and engineering discipline with measurements and reproducible outcomes. I personally think calculus in school should make way for statistics and programming. Newton and Leibniz created an amazing framework for analysing data but it's not compatible with modern tools, which are based on statistics and information.

HOW DO YOU RELAX AFTER LOOKING AT COMPLEX THEORIES?

I am a martial artist (Taekwondo), a scuba diver, and a runner. But whenever I have anxiety, I do some maths because that's a good way of channelling an overactive brain.

HOW DO YOU APPROACH SCIENTIFIC PROBLEMS AND EVERYDAY PROBLEMS?

Science is the quickest way we know to understand the environment we live in. There are other ways but they are not as efficient. Science is not perfect, but nothing is. The biggest problem with science is that it takes patience and practice to learn, but we all have the genetic predisposition to be able to understand it. Don't let anybody tell you otherwise! If you don't get on with maths and science, don't give up. You may one day land on a teacher who will truly inspire you. My biggest everyday frustration is with ignorance and people making a political point to ignore science, because I personally don't have the patience for anything else but science.



The scientific process, enhanced by machine learning.

Machine learning engineers using the Brainome Daimensions™ tool to measure and discuss the learnability of a dataset.

CAN WE LEARN TO BE SAFE ONLINE?

EVERY TIME WE LOG IN TO OUR EMAIL ACCOUNT, POST A PICTURE ON INSTAGRAM OR DOWNLOAD A NEW GAME, WE ARE PUTTING OUR PERSONAL INFORMATION AT RISK. KNOWING THAT STUDENTS CAN BE AN EASY TARGET, **PROF DOUG JACOBSON**, FROM **IOWA STATE UNIVERSITY**, USA, HAS DEVELOPED A COURSE TO TEACH COLLEGE AND HIGH SCHOOL STUDENTS ABOUT CYBERSECURITY

TALK LIKE A CYBERSECURITY SPECIALIST

Cyber attacker
The person responsible for the cyber attack, looking to make money or disrupt computing services.

Cyber attack
Intentional and malicious attempts to damage or gain access to computer systems, networks or even single devices.

Breach
Unauthorised access to private information.

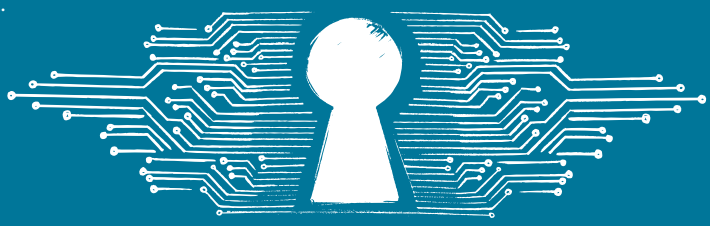
Cyber incident
A breach of security, which may include:

- Unauthorised access to a device or account
- Unauthorised use of computers to steal personal data
- Changes to software or hardware without the owner's consent.

Hacker
The person responsible for breaking into computers and networks.

Internet of Things (IoT)
In broad terms, IoT refers to everything that can connect to the internet. In everyday language, it's often used to describe items that can 'talk' to each other. The IoT is made up of all devices - such as smartphones, TVs, watches, cars and even some household appliances - connected together.

Phishing
Emails designed to trick users into giving up sensitive personal information or clicking on links to a fake website.



With the help of technology, we are becoming more connected than ever before. Undoubtedly, this progress is making our lives more comfortable, but it is also bringing a new set of challenges. Every time we log in to our email account, post a picture on Instagram or download a new game, we are putting our personal information at risk.

With so much time spent online, students are the perfect target for hackers. Because of this, Professor Doug Jacobson, from Iowa State University, knows that it is now more critical than ever before to discuss cybersecurity awareness in a school environment. However, old-fashioned methods of collecting top-ten lists of security threats or poorly organised awareness campaigns are not relevant anymore. What these students need is formal computer security education to give them the knowledge to recognise and fight these threats. Doug believes that it should be required that students learn about cybersecurity before they leave school – just as it is with subjects such as science and maths. "While technology can help keep us secure, attackers are always adapting, and we need to be vigilant," he says. "The more we know about how they attack, the better we are at defending ourselves".

PROFESSOR DOUG JACOBSON

University Professor
Director Information Assurance Center
Iowa State University, USA

FIELD OF RESEARCH

Cybersecurity

RESEARCH PROJECT

To design courses for college and high school students that teach cyber security literacy.

FUNDERS

National Science Foundation
Iowa State University

HOW CAN WE TEACH CYBERSECURITY TO STUDENTS?

Doug and his colleagues developed a module-based course to teach cybersecurity awareness to college students. The 8-week 'Introduction to Computer Literacy' course is suitable for all students, including those studying computer science and other related courses. It is natural to assume that IT students would have an advantage, but the reality is that at the beginning of the course all students demonstrated low cybersecurity literacy.

Classes are taught by a member of the Department of Computer and Electrical Engineering, who conducts demonstrations and provides real-life examples. Analysing phishing emails or guessing bad passwords are always popular activities with the students. Crucially, this allows students to experience real situations of cyber incidents in a safe and controlled manner. By the end of the course, students can recognise security threats and make sound decisions when it comes to protecting their personal information.

Interestingly, in their initial runs of the course, Doug and his team found it hard to engage with some of the students, especially when they were not from a computer background. The scientists are now developing a further section to the course, aimed specifically at these students, to help them think about how cybersecurity can be applied to their particular situation and how to avoid potential traps in the future.

"IT CAN'T HAPPEN TO ME, CAN IT?"

College students are not the only target audience that needs to learn about cybersecurity. High school pupils spend just as much time online as older students and, therefore, also need to be aware of cybersecurity issues.

It is not easy to reach these students, however. Most have an 'it can't happen to me' attitude, which teachers have trouble breaking through. For Doug, the best way to change this mentality is to present examples that are meaningful for this age group. "It is about making cybersecurity relevant to their lives," he says. For example, discussing how to keep bank account details safe will feel very alien, but the possibility of losing their Twitter or Snapchat account will quickly grab their attention.

With this in mind, the team has adapted the course material to make cybersecurity issues relevant to high school students, too. The modules are supported by detailed lesson plans, as well as videos and possible discussion topics. The new version has generally been well received by students, who seem to enjoy learning how hackers operate.

If you cannot gain access to these courses, Doug and his team are also developing a web-based version (www.security-literacy.org). The idea is to enable both teachers and students to learn about cybersecurity by themselves. Modules can be used sequentially throughout the term/semester or through a pick-and-mix approach to suit each class. Importantly, all materials are available free of charge.

For students interested in studying cybersecurity as a possible major, Doug's team has devised a project called IT-Adventures (www.it-adventures.org), which has been developed to attract more high school students to an IT field.

If you are a high school student, this may be a good way to venture into robotics and cyber defence. Form a club with your friends - it can be in school, through another group like Scouts or even home school - and register online at http://www.it-adventures.org/clubs/. Once your club is registered, you will have access to all the resources developed by Doug's team.

Unfortunately, the frequency of cyber attacks is likely to increase in the future, but this means professionals with knowledge and experience in cybersecurity will be greatly needed. In fact, the US Bureau of Labour Statistics predicts the demand for these professionals will be very high in the next few years, so it will be a good career option for students with an IT background.

ABOUT CYBERSECURITY

In the last few years, there have been several high-profile cyber attacks on multiple national and international companies. These include the attack on Twitter that affected accounts of many famous personalities like Bill Gates, Elon Musk and Barack Obama; and when a hacker known as ShinyHunters released 386 million usernames and passwords stolen from 18 different companies. Through their malicious actions, cyber criminals have accessed billions of personal records, such as emails, passwords and credit card details. With new threats appearing almost daily, there is an increasing need not only for tighter security measures but also for experienced cybersecurity specialists.

WHAT EXACTLY IS CYBERSECURITY?

Cybersecurity can be described as a way to protect information shared online from being stolen or shared without the owner's permission. With all the new devices that make up the Internet of Things, like phones and smart TVs, cybersecurity is fast becoming one of the main challenges in the modern world.

WHAT ARE THE LATEST TRENDS IN CYBERSECURITY?

Hackers commonly use automated systems to mount their attacks, which makes them very difficult to catch. But now, cybersecurity specialists are starting to use similar technologies to predict attacks and stop them before they happen.

WHAT ARE THE ESSENTIAL SKILLS TO FOLLOW A CAREER IN CYBERSECURITY?

This is a rapidly changing field, so professionals need to be able to adapt quickly to evolving threats and even anticipate them before they breach security systems. Cybersecurity specialists also need core skills like computer programming and coding, as well as risk analysis and problem solving.

HOW TO BECOME A CYBERSECURITY SPECIALIST

Maths and computer programming are the best subjects to study at school to follow a career in cybersecurity. With the increasing need for cybersecurity specialists, many universities and colleges now offer programmes in cybersecurity education. To find out more, visit: www.cyberdegrees.org/listings/top-schools.

There are also several security certifications available, such as the Certified Information Systems Security Professional (CISSP): https://www.isc2.org/Certifications/CISSP#.

According to the US Bureau of Labour Statistics, experienced cybersecurity analysts can earn up to $99,000.

PATHWAY FROM SCHOOL TO CYBERSECURITY

There are many different pathways you can take to become a cybersecurity specialist:

- Get a degree in maths, computer science or any related subject. Some employers ask for post-graduate studies, such as a Masters of Business Administration (MBA) in information systems. This two-year programme covers both business and computer courses.
- There are also several cybersecurity apprenticeships that allow participants to earn while they learn. This PDF from the National Institute of Standards and Technology, US Department of Commerce, offers some great advice: (https://www.nist.gov/system/files/documents/2018/01/09/nice_apprenticeship_one_pager_oct_31_2017.pdf)
- The final option is to work your way up with an IT security firm, gaining experience while studying for further qualifications.

DOUG'S TOP TIPS FOR STUDENTS

1 Get involved in activities that you're passionate about.

2 Explore your curiosity, learn how things work and play with computers.

3 Don't be afraid of trying things!

HOW DID PROFESSOR DOUG JACOBSON BECOME A CYBERSECURITY EXPERT?

WHAT WERE YOUR INTERESTS AS A CHILD?

I was interested in building things, whether it was building forts, playing with electronics or helping my dad with construction projects.

WHO HAS INSPIRED YOU IN YOUR CAREER?

My 9th-grade teacher got me interested in electronics when we built an electric motor. In high school, my physics teacher taught us more electronics and also arranged for a few us to get together at a local college on a few Saturdays and play on a computer. This was long before computers were in general use!

WHAT HAVE BEEN YOUR PROUDEST CAREER ACHIEVEMENTS SO FAR?

Building a new degree in cybersecurity engineering at Iowa State and launching it.

WHAT AMBITIONS DO YOU STILL HAVE TO ACHIEVE?

Getting wide-spread adoption of the cybersecurity literacy and essential materials we produce.

WHAT DO YOU FIND MOST REWARDING/CHALLENGING ABOUT YOUR WORK ON COMPUTER AND NETWORK SECURITY?

This is a field that changes every day. If cybersecurity were a game, it would be unfair since the good people can only play defence and always have to get it right. The attackers play offence. So, the best we can hope for is a draw. Working in cybersecurity helps people directly, and cyber literacy has the potential to reach a large number of people from different backgrounds and with other interests.

WHAT DO YOU FIND MOST EXCITING ABOUT THE IOT? WHAT DO YOU FIND MOST CONCERNING?

IoT can make our lives so much better by making the world more efficient and reducing time wasted. The concerning part is that these devices are often built without security in mind, and they are harder to protect since we do not directly interact with them.

WHAT WOULD MOST PEOPLE BE SURPRISED TO KNOW ABOUT CYBERSECURITY?

Most attacks target people and not computers. Attackers want information on you, rather than information on your computer.

DOUG'S SECURITY LITERACY PROJECT USES A FICTITIOUS VILLAGE, HACKERVILLE, THAT ALLOWS STUDENTS TO EXPLORE CYBERSECURITY. MEET TWO STUDENTS WHO WERE INVOLVED IN WORKING ON IT:

MELISSA HERNANDEZ

I built the CityBank site (both the real one and the 'fake' one), and I designed my own plugin for the site, which would let it act as a real banking website. It was challenging, but it was also a lot of fun.

I gained an entirely new set of technical skills from the Hackerville project. Before this summer, I had no experience with WordPress, the WordPress API, or with the Personal Home Page language (PHP). Now, I've built my plugin from scratch in PHP that allows our team to enhance the capabilities of WordPress. I feel like I've grown as a person and as a developer.

My key advice is that it is better to be safe than sorry! Taking extra security precautions online can slow you down occasionally, but it is much better to take the extra minute to answer a security question than to realise your account has been hacked.

From my experience in school, I think I may eventually end up being a mentor or a project manager. That's not something I ever planned for myself, but I'm fond of leadership and good teamwork, and I often find myself leading the team projects I'm a part of.

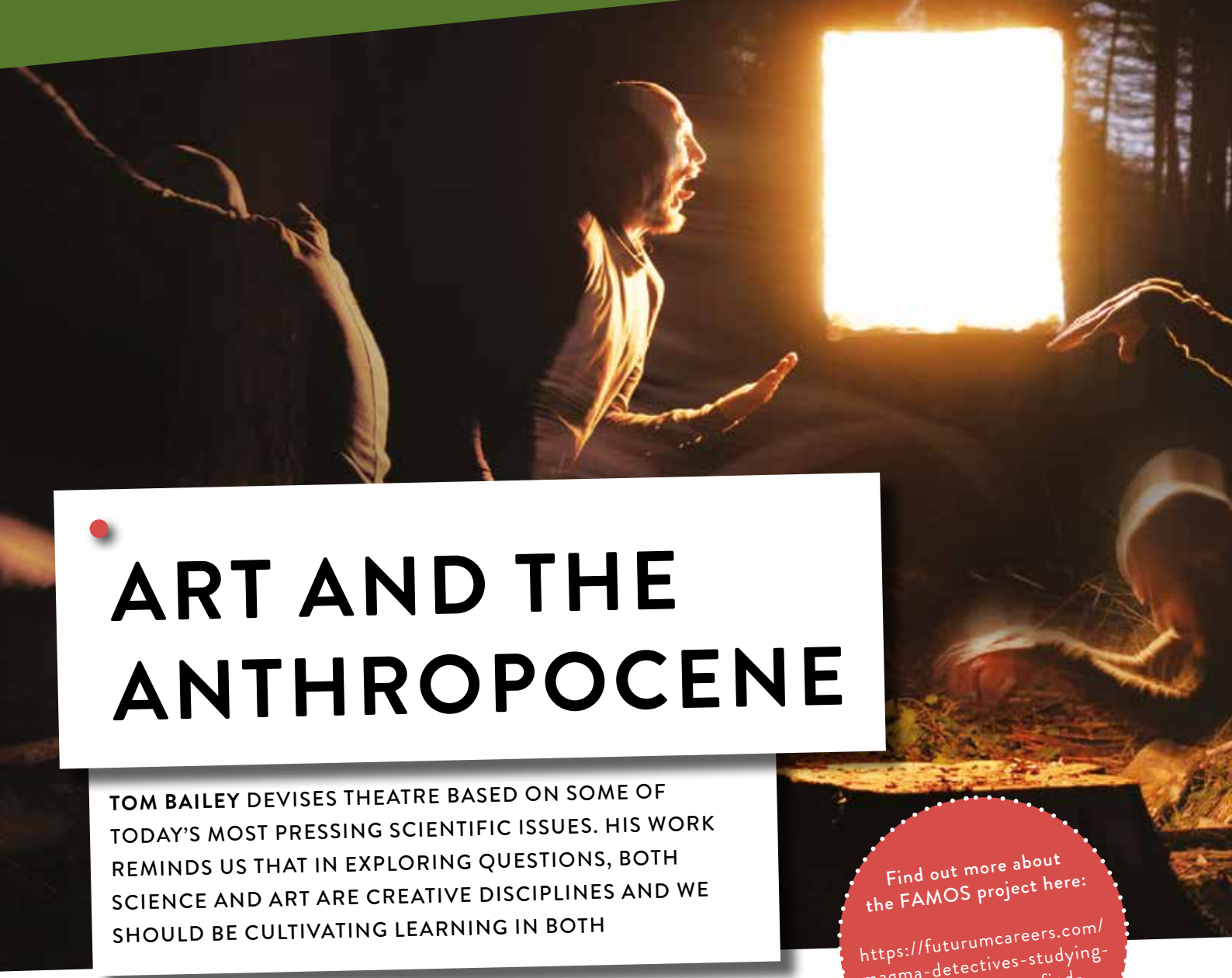
CHRIS HORVATICH

My role on the Hackerville project was to replicate common websites that people use every day, such as social media sites, to be used for training.

I gained a lot of cybersecurity knowledge as well as practical cybersecurity experience. Our project was submitted to the 2020 Summer Virtual Undergraduate Research Symposium at Iowa State University, which was a good learning experience for me as well.

I would tell young people to never forget the human element when dealing with cybersecurity issues. Your security is only as strong as your weakest link. You can throw a lot of money into technology to secure your systems, which would make people your weakest link. Malicious hackers will use phishing and social engineering to target people's laziness and fallibility. Trying to train people to be on the lookout for these attacks is the best way to prevent them.

I see myself graduating with a Major in Cybersecurity Engineering and a Minor in Computer Science. One day I hope to own a business that does cybersecurity contracting.



ART AND THE ANTHROPOCENE

TOM BAILEY DEVISES THEATRE BASED ON SOME OF TODAY'S MOST PRESSING SCIENTIFIC ISSUES. HIS WORK REMINDS US THAT IN EXPLORING QUESTIONS, BOTH SCIENCE AND ART ARE CREATIVE DISCIPLINES AND WE SHOULD BE CULTIVATING LEARNING IN BOTH

Find out more about the FAMOS project here:

https://futurumcareers.com/magma-detectives-studying-volcanic-arcs-to-find-valuable-minerals-in-earths-crust

Making theatre from scratch, not following a script, is a long but rewarding process for Tom Bailey, a director and theatre maker based in Bristol in the UK. As might be expected, part of his creative process – that focuses on the use of body, rhythm and tempo – is collaborating with other creatives, such as sound designers and movement directors, but that's not where his collaborations end. As well as doing his own research, Tom works with scientific researchers to ensure his performances explore thought-provoking and contemporary scientific issues. His current work on the FAMOS research project – that aims to understand the processes that cause metals to be concentrated in magmatic arcs – is evidence of his desire to use his art to connect people with important scientific questions that affect us all.

WHY DO YOU FEEL THE PUBLIC NEEDS TO ENGAGE WITH THE ISSUES RAISED BY FAMOS?

Copper mining, and resources mining in general, is fundamental to modern civilization. Yet, in general, the public is disconnected from seeing how all of our computers, phones, cars and daily lives are dependent, in some way, on mining. Technology relies on a global network of organisations transforming rock into metal. The more the public can engage with this, the more sensible the debate can be around the vital role of mining during this time of climatic change. We need to connect with how mining affects us, and how we affect mining by the decisions we make, the values we have as a society, and the things we buy and use.

WHAT DO YOU HOPE YOUR AUDIENCES WILL GAIN FROM YOUR WORK?

I don't make theatre to communicate science. Science communicators communicate science. Theatre for me has a different role. It's about feeling and experiencing, asking more questions, being curious. So, I hope that I can offer an experiential encounter with rocks, mining and copper for audiences, that they won't encounter anywhere else. This experience has to tap into the audience's imagination in a way that no other art form can.

As an artist, I'm excited when working with scientists, exploring the intersection between the known and the unknown, and the limits of present knowledge. I think it's a really interesting place where arts can engage with science. Both ask questions about the unknown, but in different ways. I think one is more about knowing, the other is more about experiencing.

AS A THEATRE MAKER, WHAT HAVE YOU GAINED FROM EXPLORING THE FAMOS PROJECT?

The ability to explore the fascinating world of geology with some amazing researchers. A deep encounter with rocks is transformative, because they can make you more aware of scale – both size and time – and how small human timeframes and human civilization can be against the immensity of geological force and geological time. During our Anthropocene age, this is an important experience for me.

ABOUT TOM BAILEY

Director and Theatre Maker

"ROCKS AND STONES CARRY THEIR OWN MAGIC, LIKE SMALL FRAGMENTS OF TIME. THEY HOLD MILLIONS OF YEARS OF HISTORY IN THEM, WHICH IS WHY I LOVE WORKING WITH THEM."

ABOUT TOM AND HIS WORK

1. WHAT DO YOU FIND MOST REWARDING ABOUT BEING A THEATRE MAKER?

Being creative for a job, telling stories to gatherings and communities of people, offering people unusual experiences that move, excite and make them laugh.

2. WHO OR WHAT HAS INSPIRED YOU IN YOUR CAREER?

- **James Lovelock** – a brilliant scientist, climate systems thinker and originator of the Gaia Theory. He inspired me to look at the Earth in a different way.
- **Jerzy Grotowski** – an amazing Polish theatre director and thinker, most active in the 1960s-1980s, who pioneered new ways of creating theatre through physical training and research.
- **The Buddha**.
- My English teacher at school, **Mr Selwyn**.
- Contemporary landscape artists such as **Andy Goldsworthy** and **Richard Long**.
- **Landscapes** – the Western Isles of Scotland, Neolithic sites in the Southwest of England, and tropical areas of Brazil remind me that nature can be a work of art in itself.

3. WHAT CAN BE DIFFICULT IN YOUR WORK AND HOW DO YOU OVERCOME OBSTACLES?

It generally comes down to two things: people and money. If you can get along with different people and navigate personal differences, and if you can work out how to create art frugally and how to receive arts funding from different sources, then you can overcome the first two obstacles of freelance, devised theatre making.

Secondly, a challenge is finding a way in, as an artist, to the science and research. Often, amid a wealth of information, research, resources and possibilities, it's about searching for that one thing that really excites you, that makes you really passionate about the subject. This can sometimes be hard to find. You have to trust that the show won't always come easily. Sometimes, you find what the show is early on, and rehearsals are much easier going. Sometimes, it's a slog to find the core of the show, and you have to accept that you're going to make many wrong turns before finding what the show really is.

4. WHAT PROJECTS ARE YOU AIMING TO WORK ON IN THE FUTURE?

I'm creating two new shows at the moment - this mining project, and another one called Ghost Sonata, exploring the current transformation of the Arctic. I'll also be touring existing shows that look at species extinction and bird migration.

TOM'S TIPS

• Do what you can to cultivate learning and appreciation in both arts and sciences for as long as possible. This leads to greater skills and appreciation in both.

• There is more money in science because we live in a society that places higher value in technological and scientific work than artistic work. It hasn't always been like this, and this needs to change. We need more artists - be part of that change!

Tom's current work is based on the FAMOS research project and explores our reliance on mining for resources.

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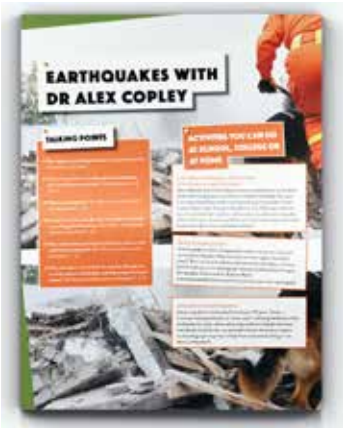

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