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Know what you want to be

A SCIENCE, RESEARCH AND TECH MAG
FOR THE NEXT GENERATION

ISSUE 2
JUNE 2019

WHERE WILL STEAMM TAKE YOU?

IN THIS ISSUE:

18 AWESOME RESEARCH PROJECTS
TAKE PICTURES IN SPACE WITH THE WORLD'S LARGEST TELESCOPE

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STEM AMBASSADORS ARE COMING TO A SCHOOL NEAR YOU

EXCLUSIVE INTERVIEWS
A RAP ARTIST AND CAVE RESCUE DIVER TALK STEM

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WHERE WILL STEAMM TAKE YOU?

If you're between 11-19 years of age, you'll have already decided whether you like science and maths or not. Chances are you don't – or, at least, you think these subjects are hard and irrelevant. That's what the statistics say, anyway. But you're not a statistic. You're you. And you've got your whole future ahead of you.

So, what do you want to be? And, have you connected the dots between what you think you want to be and what makes you happy? Because truly knowing what you want to be means that you know yourself and the world around you. You know what you're good at, and you know about all the amazing jobs out there.

If you've connected the dots, you know that science isn't just science. It's connected to everything – music, art, nature, food, gaming, mobile phones, space – and you. This is what Futurum is about. Connecting the dots so you know – truly know – what you want to be.

In this edition of Futurum, you'll find:

- Easy-to-read research articles, including interviews with scientists
- Interviews with students studying STEAMM (science, tech, engineering, arts, maths, medicine)
- Articles on STEAMM organisations that offer free youth and education resources

Go online, and you'll discover activity sheets to accompany each and every one of the articles in this magazine.

We also encourage you to get involved. You can sign up to our monthly newsletter, comment on the articles online, and follow and share our posts on social media

We hope you enjoy this first issue of Futurum!

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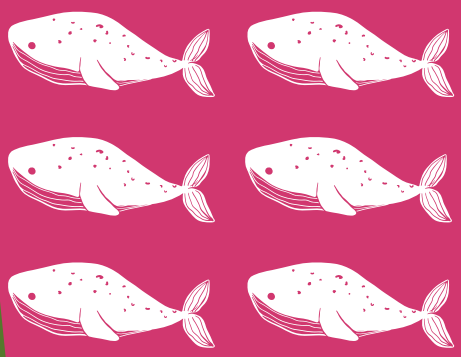
CAN STORM WAVES MOVE A BOULDER AS HEAVY AS SIX BLUE WHALES?

SCIENTISTS USED TO THINK THAT ONLY TSUNAMIS WERE CAPABLE OF MOVING GIGANTIC ROCKS FAR INLAND AND ABOVE HIGH WATER. GEOLOGIST **DR RÓNADH COX** NOW HAS THE EVIDENCE TO PROVE THAT STORM WAVES CAN BE JUST AS POWERFUL

IMAGINE THIS

Imagine a rock weighing 620 tonnes. That rock will be four times heavier than a house, or about the same as six blue whales. Now visualise ocean waves rolling toward the shore. Imagine the waves crashing against that rock so strongly that they're able to move it. Storm waves can unleash tremendous energy on coastlines, but the extent of the damage they can do is only beginning to be understood.

More than 600 million people (around 10 per cent of the world's population) live in coastal areas less than 10 meters above sea level. That's a lot of people vulnerable to storms. So, it's the job of scientists to make sure that we understand how big and energetic storm waves can get.



West of Ireland, three rocky isles known as the Aran Islands guard the mouth of Galway Bay. Each island is home to a few hundred people, who live on the sheltered eastern sides, and to thousands of gigantic boulders on the exposed west coasts. For a long time, some scientists thought that these boulders were too huge to be moved by storms, and assumed that they had been left behind by an ancient tsunami. But recently, geologists showed that this assumption was wrong. In 2013-14, a set of very strong storms battered the islands, shifting boulders way above the shoreline: some were on 26-metre-high cliffs, and others were almost a quarter of a kilometre inland. Some of the boulders weighed 10s or 100s of tonnes. The largest was 620 tonnes.

HOW DID RÓNADH'S TEAM PROVE THE ROCKS HAD MOVED?

The key evidence came from before-and-after photographs that were linked to map locations. Back in 2008, Rónadh visited the area with a student, Danielle Zentner, to study the boulders. They were looking for hard evidence of whether tsunami or storm waves had moved these huge rocks, and so they began to measure, photograph and map the locations of boulder deposits on the Aran Islands. More students took an interest in the project, and over the years they gathered key information, including the weight and precise locations of thousands of boulders, and photographed them.

After the big storms hit the west coast of Ireland in 2013-14, Rónadh returned to the Aran Islands with a team of seven students. This time, they were armed with photographs and measurements. The research team visited all of the sites and compared the photographs they had from previous years (on iPads) with the locations of boulders. It was apparent that many boulders hadn't moved. But many others had: some had travelled 10s of metres, some had been hoisted up and over other boulders, and some had disappeared entirely! In places, solid bedrock had been ripped up to make new boulders.

"We were able to make graphs – simple XY plots – showing relationships between boulder weight and distance inland, height above sea level, and coast steepness – and also between those topographic variables and the distance the boulders moved. These are very basic measurements and diagrams (not rocket science!), but nobody had shown these relationships before," explains Rónadh.

WHY DID PEOPLE THINK A TSUNAMI HAD MOVED THESE BOULDERS?

"Storm waves have shorter periods than tsunami," says Rónadh. The period is the amount of time a wave takes to pass a point. Big storm waves can take 10-15 seconds, but a tsunami is much longer, lasting many minutes. Tsunamis are destructive because the flow of water continues for a long time, engulfing and pushing objects as it goes. But because storm waves at the coast form surf that flows in and out in just a few seconds, people thought they lacked the sustained force to dislocate giant blocks. Thanks to Rónadh and her students, we now understand more about the power storm waves and surf can exert.

WHY IS IT IMPORTANT TO STUDY BOULDER MOVEMENT?

Scientists have been studying transport of sand

Measuring rocks with attitude!

and small rocks on coastlines for a long time, so we know lots about the impact of storms on beaches in coastal areas where people live. These places tend to experience lower-energy waves compared to areas such as the Aran Islands. But as sea level rises, and climates change, it's possible that storminess may increase. We therefore need to understand the highest wave energies, to understand how much coastal damage storm systems can cause.

Before Rónadh's research was published, people didn't realise that storm waves could move boulders as heavy as six blue whales – or heavier. The largest boulder on the Aran Islands weighs more than 700 tonnes. It didn't move during the 2013-14 storms, but evidence shows that it moved in the past. If scientists are to accurately understand and predict risks associated with living in coastal areas, understanding boulder transport is vital. And the world needs more geologists to work on these problems!

DR RÓNADH COX

Edward Brust Professor of Geology and Minerology
Williams College, USA

FIELD OF RESEARCH

Geology

RESEARCH PROJECT

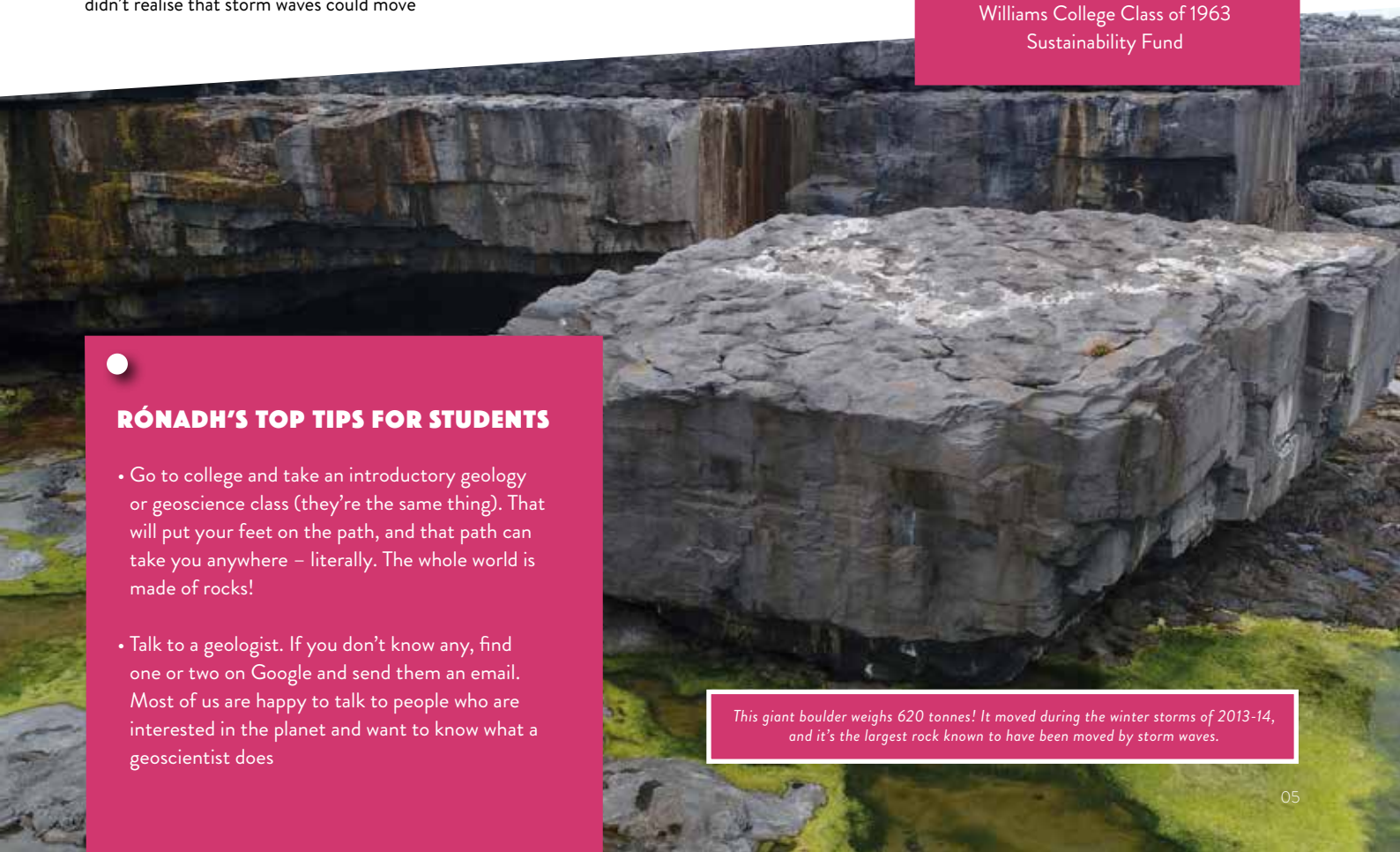
Rónadh and her team of students have measured, photographed and documented the location of over 1,100 giant boulders that were moved by storms on the west coast of Ireland. Her work has helped prove that storm waves can move rocks weighing hundreds of tonnes.

FUNDERS

National Science Foundation and Williams College Class of 1963 Sustainability Fund

RÓNADH'S TOP TIPS FOR STUDENTS

- Go to college and take an introductory geology or geoscience class (they're the same thing). That will put your feet on the path, and that path can take you anywhere – literally. The whole world is made of rocks!
- Talk to a geologist. If you don't know any, find one or two on Google and send them an email. Most of us are happy to talk to people who are interested in the planet and want to know what a geoscientist does



This giant boulder weighs 620 tonnes! It moved during the winter storms of 2013-14, and it's the largest rock known to have been moved by storm waves.

ABOUT GEOLOGY

Rónadh has been studying and working in geology for nearly 40 years. We ask her why becoming a geologist is a good career choice.

WHY DO WE NEED GEOLOGISTS?

Lots of reasons! But here are a couple. First, most of our natural resources come from the Earth. As the saying goes: 'If it can't be grown, it must be mined'. From the metal in your fizzy drink can, to the necklace around your neck, to the 70+ components in a computer screen, a geologist had to figure out where to find the ores to create all these things.

Second, we live in a dynamic world, subject to floods, landslides, earthquakes and eruptions. Geologists are the people who try to understand these processes, and help communities decide how to manage natural hazards and where to build.

WOULD YOU SAY GEOLOGY, OR THE GEOSCIENCES, OFFER GOOD JOB PROSPECTS?

Very much so. You can get a geology job with just a bachelor's degree. And if you decide to pursue an advanced degree, you can get paid to do that. Students are awarded fellowships to cover tuition costs and are paid a salary. Graduates go into teaching, environmental engineering, resource exploration, conservation, management, climate science – all kinds of things. Some even use their geology background to kick start careers in law or politics.

WHAT EXCITES YOU ABOUT YOUR RESEARCH AND GEOLOGY, MORE GENERALLY?

Geoscience teaches us to look at the planet and ask questions. I love to walk around wondering how things formed. People who know geologists joke that you should never drive with them, because they spend all their time looking out of the window at rocks instead of watching the road. Geology makes the world come alive!

> *"Geologists get jobs with just a bachelor's degree, but if you decide that you want to move on to an advanced degree, you can get paid to do that."*

Rónadh's team of undergraduate field researchers stands next to a truly titanic boulder.

Along the Aran Islands' Atlantic coast, there are 15 km of boulder deposits.

Piles of boulders sit on top of 40 m cliffs, 25 m inland from the edge. To understand the scale of this, look at the people near the cliff edge.

Find this article online and download the activity sheet: https://futurumcareers.com/can-storm-waves-move-a-boulder-as-heavy-as-six-blue-whales

ASK DR RÓNADH COX

WHAT DID YOU WANT TO BE WHEN YOU WERE YOUNGER?

I always wanted to work in the natural world. I was fascinated by stories of adventure and exploration, and also by animals. Initially, I wanted to be a marine scientist or a biologist.

SO, HOW DID YOU END UP FOLLOWING IN CAREER IN GEOLOGY?

I went to college planning to get a degree in biology and hoping to have a career that would involve adventure and exploration outdoors. I took geology as my fourth course because I didn't want to do physics (I've always been shy of maths, although over the years I've discovered that maths is pretty badass!) It didn't take long, just a few weeks, before I was sucked in by the concepts of plates, earthquakes, deep time and the way the earth works.

YOU GREW UP IN IRELAND. WHY DID YOU CHOOSE TO STUDY AND WORK IN THE US?

I went to University College Dublin and had never lived anywhere else. When I decided to do a PhD, I thought it would be fun to live and work in a foreign country, so I applied to universities in the US. I had planned to come home to Ireland after I got my degree, but I met my husband in graduate school. He's also a geologist, and we both wanted to work in research and teaching. The US is where we both managed to find college jobs.

YOU'RE CURRENTLY BASED AT WILLIAMS COLLEGE, IN MASSACHUSETTS, USA. WHY ARE YOU STUDYING BOULDERS ON THE WEST COAST OF IRELAND?

My motto is: 'The whole world is made of rock. Why not study it someplace interesting?' Geoscience is a ticket to anywhere and everywhere. I'm studying the west coast of Ireland because it turns out that its boulders are some of the most impressive in the world.

WHAT DO YOU LOVE MOST ABOUT YOUR JOB? AND WHAT ARE YOU NOT SO KEEN ON?

I love field research. I love teaching students. I especially love teaching students in the field. I love solving puzzles about how the Earth works. I love that I get to walk along some of the most beautiful coastlines in the world, and that I get paid to do it! #theWorldIsMyOffice. I don't like grading and I don't like administrative work, but you gotta do what you gotta do.

IF YOU COULD GO BACK IN TIME WHAT ADVICE WOULD YOU GIVE YOURSELF WHEN YOU WERE STARTING OUT ON YOUR CAREER PATH?

Take chances! Don't be afraid to make mistakes or to fail. But own your mistakes and your failures; learn from them and move on. Your failures don't define you, but they can make you stronger and help you create your successes. It took me six years to get my four-year degree because I failed courses and made bad choices and prioritised social life over work. But I learned, I grew up, and here I am. It's all good!

OPPORTUNITIES IN GEOSCIENCES

- According to GlassDoor, geologists with just a bachelor's degree earn $63,000 on average
- Some industries pay more. For example, government geologists earn on average $103,000 or more (FederalPay.org), and geologists in the oil industry earn on average $150,000 per year
- Lots of employers seek people with a degree in geoscience. The energy sector (oil, gas, wind, waves) and environmental firms hire geologists, but there are also opportunities elsewhere. The National Park Service, for example, offers paid internships for college students and recent graduates
- It's important to remember that students enrolled in geoscience PhD programmes are usually paid while studying for their degree (see PhD Stipends)

Meet JoJo. She's on a field expedition studying boulder erosion. You can be a field geologist, too, and measure the natural world.

STUDYING EARTHQUAKES TO SAVE LIVES

EARTHQUAKES OCCUR OFTEN, AND THEY CAN WREAK HAVOC ON INFRASTRUCTURE SUCH AS BUILDINGS AND ROADS. OF COURSE, EARTHQUAKES ARE A NATURAL OCCURRENCE, BUT HOW CAN CITY PLANNERS AND CONSTRUCTION COMPANIES PREPARE FOR THEM AND MINIMISE THEIR IMPACT? **DR ALEX COPLEY** FROM THE **UNIVERSITY OF CAMBRIDGE** THINKS A DEEP UNDERSTANDING OF EARTHQUAKES, BOTH PAST AND PRESENT, IS KEY

IMAGINE THIS

We often hear reports of devasting earthquakes; seemingly in one place after another. Last year, for example, a 7.5 magnitude earthquake struck Indonesia's Central Sulawesi region, killing over 2,000 people and injuring many more. The Haitian earthquake of 2010 and the Sumatran earthquake of 2004 are two of the deadliest in recent history – each resulting in the loss of over 220,000 lives. But the deadliest earthquake we know about occurred in the Chinese province of Shaanxi in 1556, killing around 830,000 people.

According to the Incorporated Research Institutions for Seismology (IRIS), on average, 'major earthquakes' (those greater than magnitude 7) happen more than once a month. 'Great earthquakes' (those greater than magnitude 8) occur about once a year.

Earthquakes have devasting effects on communities around the world. Not only do they result in casualties, they can cause damage to vital infrastructure, housing and other basic services. So, it's important that city planners and construction companies think about potential future earthquakes when they plan and construct buildings.

Dr Alex Copley has been studying earthquakes and their effects for many years. He feels that a greater understanding of earthquakes, and incorporating that information into any planning and construction projects, will improve building practices and minimise the negative impacts of earthquakes.

WHAT IS AN EARTHQUAKE AND WHAT CAUSES THEM?

The term 'earthquake' refers to rocks breaking within the Earth's interior, leading to the violent shaking, quaking or rolling of the Earth's surface. These breaking rocks are caused by movements within the Earth's crust, or as a result of volcanic activity. Earthquakes occur at various locations around the world and without warning. Those that occur in built-up areas are particularly devastating.

Earthquakes typically happen in areas of intense geological activity. For example, many occur along what's known as plate boundaries. To understand what plate boundaries are, and why earthquakes happen there, we need to know a little bit about the structure of the Earth. The Earth's crust, or outermost layer of rock, is not in one piece. Rather, it's made up of lots of massive, interlocking pieces of solid rock called tectonic plates. These tectonic plates are floating on softer rock below. Plate boundaries are the areas where tectonic plates meet.

At these boundaries, huge slabs of rock are squeezing past each other. Sometimes they get stuck, but the forces pushing on the rock slabs keep on pushing. A huge amount of stress builds up between the stuck sections of rock. Eventually, the rocks bend so far that they break and release all of the pent-up energy (i.e. an earthquake), just as it would if you bend and break a plastic ruler. Because the pieces of rock are so huge, the resulting movement sends large shock waves through the Earth.

WHY DO SCIENTISTS MONITOR EARTHQUAKES?

When an earthquake strikes, particularly in cities such as Tokyo or Los Angeles, it's hard to believe that millions of people chose to live there. But the time between repeated earthquakes in one place is usually long compared with human life-spans, meaning that many cities were established without truly understanding the risks. To help people to understand these risks and prepare for future events, researchers such as Alex are essential.

Although scientists don't know when exactly earthquakes will occur, they can estimate where they'll happen, and roughly how big

they'll be. This is useful information, indeed. "The information about the locations and sizes of earthquakes are the key things that we need to know in order to allow people to design earthquake-proof buildings. City-planners need this information, for example, especially in earthquake-prone regions," says Alex. In fact, planning construction work around potential earthquake threats has already been successful in many places: such as Japan, the US and Chile.

HOW DO SCIENTISTS MONITOR EARTHQUAKES?

"One approach is to look at earthquakes that have occurred recently and use this information to understand more about what controls the sizes, locations and characteristics of the events," Alex explains.

Scientists even go way back in time – going deep into the geological record to find signs and evidence of prehistoric earthquakes. All this information paints a picture of the area's seismic history. "Similar earthquakes occur repeatedly in the same places, often many years apart, so by looking at these prehistoric earthquakes we can get an idea of what might happen in the future," says Alex.

WHAT IMPROVEMENTS WILL WE SEE IN THE YEARS TO COME?

Alex and other scientists are working with governments and policymakers (the people responsible for making new rules) to understand the causes and consequences of earthquakes. Although doing so takes a lot of time and effort, it's very much worthwhile. Buildings can be built to be stronger, made from better materials and put in more suitable locations. Ultimately, improved town planning and building design will save lives and minimise disruptions to communities.

Alex admits that, "the work of scientists on this front has been successful in some places, but we have struggled in others. That said, I'm confident that with continued efforts, the world will become a safer place."

DR ALEX COPLEY

Earth Scientist
University of Cambridge
Cambridge, UK

FIELD OF RESEARCH

Earthquakes and Tectonics

RESEARCH PROJECT

Alex researches earthquakes, past and present, and their impacts on affected communities. Armed with this understanding, he aims to help urban planners and construction companies to plan and build earthquake resistant buildings. Improved construction practices will, in turn, prevent casualties and damage to vital infrastructure during future seismic events.

FUNDERS

Natural Environment Research Council (UK), European Commission

This mountain in Albania has been produced by many earthquakes lifting up one side of the fault over millions of years.

ABOUT EARTH SCIENCE

Earth science is a broad area of science that encompasses many different subjects. Scientists like Alex, for example, work on understanding geological hazards such as earthquakes, volcanoes, landslides and floods. Others work on understanding the past and present climate, and the environmental impacts of human activities. For young people considering a career in Earth science, there are a range of career paths open to them, including those that revolve around natural resources such as water, minerals, hydrocarbons and energy.

WHAT ABOUT THE STUDY OF EARTHQUAKES? IS THIS A FIELD THAT NEEDS MORE SCIENTISTS?

The study of earthquakes and tectonics comes under an area of research known as seismology. Seismologists study earthquakes, the factors contributing to their size and severity and the impacts on affected communities.

Many universities and government agencies are committed to the study of earthquakes. Due to the sheer size of the Earth, the number of interesting sites to investigate and the complex tectonic processes involved, there's no shortage of earthquake research to be done!

"The continuing increase in the global population, and all of the building that is associated with this increase, means that there's a race against time to understand enough about earthquakes to ensure that all the new buildings will be able to keep their occupants safe," says Alex. "This means that there's a lot of work to be done in earthquake science, and plenty of opportunities for enthusiastic people!"

WHAT SUBJECTS SHOULD YOU TAKE IF YOU'RE INTERESTED IN EARTH SCIENCE?

You can undertake secondary studies in geology (Earth science) at A level in the UK. This is also the case in many other countries such as Australia. But you'll find that Earth science is strongly connected to many other STEM topics such as physics, chemistry, biology and maths. Most people who study Earth science at university haven't studied it at school, but have a background in other STEM subjects.

OPPORTUNITIES IN EARTH SCIENCE

- In most cases you'll need a bachelor's degree in Earth science/geology or physics to get entry-level jobs in the Earth sciences. To specialise and become a seismologist, though, you'll need to do a Master's degree in Earth sciences that includes some seismology. To enter research, a PhD is this area is usually required
- The typical salary for a seismologist or geoscientist depends on the sector they work in. For example, those working in the energy sector tend to be paid more than those working for educational or government organisations. According to The Geological Society, qualified geoscientists started on a salary of around £28,000-£35,000 in 2015, increasing to £40,000-£70,000 with more experience

A scarp (steep slope) in the landscape produced by an earthquake in the Andes mountains, Peru

Alex Copley and his colleague Al Sloan doing earthquake research in India

ASK DR ALEX COPLEY

WHAT DID YOU WANT TO BE WHEN YOU WERE YOUNGER?

I initially wanted to be either a sheep farmer or a train driver! In my teens I started thinking about doing something involving physics, because I enjoyed it at school. However, a chance encounter with a teacher at a school open day inspired me to do geology at A level, and I was so hooked that I've been doing it ever since. I think it's always worth keeping an open mind about subject choices!

WHAT IS IT ABOUT EARTHQUAKES THAT FASCINATE YOU?

I think it's the combination of trying to understand a fascinating process in a situation that can also make a real improvement to public safety. One of the big reasons I find the research so captivating is that in Earth science many of the major research topics deal with things we can see, and visit; I find that much more exciting than dealing with abstract concepts.

COULD YOU CALL YOURSELF AN 'EARTHQUAKE HUNTER'?

I would say completely the opposite! Our earthquake monitoring is advanced enough that we very rapidly know where and when significant-sized earthquakes have occurred. Part of my research is to sift through all this information, and to decide which are the interesting events for which detailed research will teach us more about earthquakes in general.

HAVE YOU EVER BEEN NEAR AN EARTHQUAKE? WHAT DOES IT FEEL LIKE?

The first earthquake I felt was a little one in eastern England in 2008. Since then, I've felt quite a few, especially when I spent some time living in California. The ones I've experienced, and that have been nearby, have felt like I was being rapidly shaken by someone. The ones further away feel more like going up and down on ocean waves in a boat. Thankfully, I've never felt a big one at close range, which is when the destruction happens.

WHAT DO YOU LOVE MOST ABOUT YOUR JOB?

I love that the university employs me to do something that I find so interesting. It would probably be a hobby even if I did a different job. The flexibility of academic life – i.e. thinking about and researching the things I find most interesting – is also fantastic.

IF YOU COULD GO BACK IN TIME WHAT ADVICE WOULD YOU GIVE YOURSELF WHEN YOU WERE STARTING OUT ON YOUR CAREER PATH?

I was initially very shy when I was doing my degree and PhD, so I'd tell myself to believe that what I have to say is worth hearing, and to speak up when there's an opportunity to make a positive contribution.

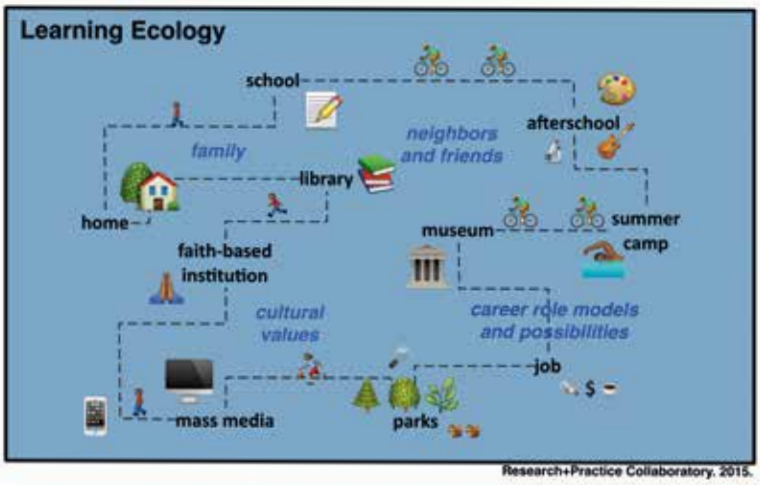
Alex Copley is studying the signs of past earthquakes in a trench dug across an active fault line in Greece.

SCIENCE BEYOND THE SCHOOL GATES

CONNECTED SCIENCE LEARNING **IS ONE OF THE NATIONAL SCIENCE TEACHERS ASSOCIATION'S FIVE JOURNALS, AND ITS ANALYSIS OF EXTERNAL STEM EDUCATION PROGRAMMES IS PROVING JUST HOW IMPORTANT IT IS TO PUSH SCIENCE LEARNING BEYOND THE SCHOOL GATES. DENNIS SCHATZ, NSTA PRESIDENT-ELECT AND FIELD EDITOR OF *CONNECTED SCIENCE LEARNING* EXPLAINS**

CONNECTED SCIENCE LEARNING (CSL) IS A JOURNAL, PUBLISHED BY THE NSTA AND ASSOCIATION OF SCIENCE-TECHNOLOGY CENTERS, THAT HIGHLIGHTS THE CONNECTION BETWEEN LEARNING SCIENCE IN AND OUT OF CLASSROOMS. WHY IS IT IMPORTANT TO RECOGNISE AND NURTURE THIS CONNECTION?

The value of connected science learning is well documented in the first Research to Practice article in Issue 1 of the journal. It highlights how learning occurs across physical settings, social interactions, value systems and histories – including learning over time, throughout the day, week and lifespan. An illustration in the aforementioned article does a nice job of showing the many ways and places learning occurs:



Effective STEM learning should take advantage of the time out of school to build a lifelong enthusiasm for STEM, as well as give our youth the skills needed to be successful members of the modern workforce.

WHEN WAS _CSL_ SET UP, AND WHO IS IT AIMED AT? WOULD YOUNG PEOPLE BE INTERESTED IN READING A COPY?

CSL started with a National Science Foundation (NSF) award, granted in 2014. The first issue was published in March 2016. It is aimed at STEM programme developers in both schools (e.g. science specialists, district science coordinators) and out-of-school settings (e.g. museums, afterschool programmes). In addition, the journal is useful to policy makers, corporations, foundations and others seeking to identify, advance and invest in STEM education. It is not a journal that many young people would find interesting.

ABOUT DENNIS SCHATZ

"When elected this year, I committed to three years as President-Elect (2018-2019), President (2019-2020), and Retiring President (2020-2021). Much of this year will be spent learning the multiple responsibilities of the President. In addition, it is a time to represent the National Science Teachers Association (NSTA) in a number of professional venues, to assign new members to NSTA committees and organise next July's National Congress on Science Education."

ABOUT THE NATIONAL SCIENCE TEACHERS ASSOCIATION

The Arlington, VA-based National Science Teachers Association is the largest professional organisation in the world promoting excellence in science teaching and learning, pre-school through to college. NSTA's membership includes approximately 50,000 science teachers, science supervisors, administrators, scientists, business representatives and others involved in science education.

www.nsta.org

> *"Effective STEM learning should take advantage of the time out of school to build a lifelong enthusiasm for STEM, as well as give our youth the skills needed to be successful members of the modern workforce."*

WHAT MOTIVATED ITS LAUNCH?

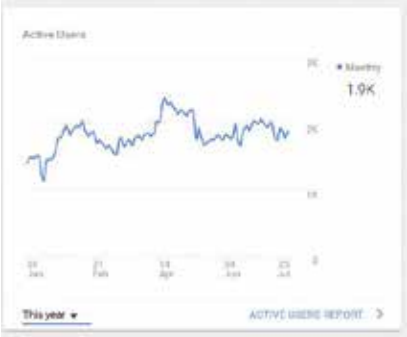
Leaders at NSTA and NSF realised that educators (both in and out of school) needed to see effective in- and out-of-school STEM learning programmes in order to appreciate their value.

WHAT DOES THE JOURNAL OFFER TEACHERS THAT THEY MAY NOT FIND ELSEWHERE?

There is no one place where educators can learn about STEM learning programmes that bridge between in-school and out-of-school venues. *CSL* provides this resource. Moreover, *CSL* specifically focuses on the methods, resources and even the challenges associated with developing programmes that connect in-school and out-of-school STEM learning. This focus is not seen in other websites or publications.

HOW POPULAR IS *CSL*?

Much of 2016 and 2017 were experimental years to develop the publication approach and look. Formative evaluation showed there was interest in the journal's subject area not covered by other media. We were delighted that in the first six months of this year, *CSL* saw a more than 10% increase in subscribers – from 3,500 to 3,914. In addition, the number of active users (number of unique visitors per month) increased by 36% from approximately 1,400 to 1,900, according to Google Analytics (see the graph below):



HOW DO YOU ACCESS THE JOURNAL AND HOW OFTEN IS IT PUBLISHED?

It is an online journal that can be found on the NSTA website at http://csl.nsta.org. You can also find more information about the journal, including the Call for Contributions and Submission Guidelines: https://www.nsta.org/publications/csl/. Four issues are published each year, with each issue serialised into three parts, so that a selection of articles is published every month.

Place-based education: © NEMIGLSI

Dragonfly Detectives. Photo courtesy of Christine L. Goforth

EASY AS ONE-TWO-THREE

ALL OF THE PROGRAMMES FEATURED IN *CSL* ARE TRULY INSPIRATIONAL. THESE THREE INITIATIVES – ALL THE SUBJECT OF *CSL* ARTICLES – ILLUSTRATE JUST HOW SUCCESSFUL OUT-OF-SCHOOL LEARNING CAN BE FOR FOSTERING AN INTEREST IN STEM

GREAT LAKES STEWARDSHIP INITIATIVE – NORTHEAST MICHIGAN

"Imagine kids whose classrooms are their neighborhoods, who are engaged in hands-on projects that help them create change right where they live." This is the mission statement on the homepage of the Great Lakes Stewardship Initiative (GLSI). It is also the thinking behind place-based education – a process that connects students with their local environment by addressing real community issues whilst also meeting rigorous education requirements.

CSL focused on one of the Initiative's nine regional hubs – Northeast Michigan GLSI – and used cases studies to show how place-based education can meet the region's literacy goals as well as provide environmental science, technology, engineering and maths opportunities.

https://greatlakesstewardship.org

DRAGONFLY DETECTIVES

An afterschool citizen science programme for children aged 9-14, Dragonfly Detectives' aim is to turn North Carolina's kids into scientists. Set up by the North Carolina Museum of Natural Sciences, the programme gets students to do what it calls REAL science: "The kind of science where we don't know all the answers and will learn brand new things about our world from the information we gather together".

CSL took an in-depth look at the Dragonfly Detective's delivery and outcomes, concluding that the programme effectively engages children in authentic science.

https://dragonflydetectives.wordpress.com

COLORADO BIOSCIENCE INSTITUTE – RESEARCH EXPERIENCE FOR TEACHERS

The idea behind Research Experience of Teachers (RET) programmes is to give teachers first-hand knowledge of what it's like to do science in the real world. By having an opportunity to work with scientists in their labs, teachers can then translate their experience to the classroom – with help from programme experts.

CSL explored Colorado Bioscience Institute's RET programme, which not only supports middle and high school teachers, but also offers mentoring for undergrad and graduate students, as well as leadership and workforce development trainings for science professionals at any stage in their careers.

www.cobioinstitute.org/research-experience-for-teachers

BUSTING MYTHS ABOUT STEM CAREERS

DR AJAY SHARMAN, STEM LEARNING'S NETWORK LEAD FOR LONDON AND SOUTH EAST, TELLS US ABOUT THE CRUCIAL ROLE OF THE STEM AMBASSADORS PROGRAMME IN OVERCOMING STEREOTYPES ABOUT SCIENTISTS, TECHNOLOGY SPECIALISTS, ENGINEERS AND MATHEMATICIANS

STEM LEARNING'S VISION IS TO ACHIEVE WORLD-LEADING STEM EDUCATION ACROSS THE UK. It's about giving young people opportunities to be inspired and motivated to study STEM subjects, ultimately leading them into STEM careers. We don't just support teachers, we also work with a wide range of youth and community groups. STEM Learning is a unique organisation in terms of what it does and its links to education, business and universities.

STEM LEARNING HAS A WHOLE HOST OF PROGRAMMES AND INITIATIVES DEDICATED TO THIS. From continuing professional development (CPD) for teachers and support staff to STEM Ambassador role models from industry; all of our programmes are designed to have a positive impact on those who work with young people, and ultimately on the young people themselves.

> *"STEM Ambassadors come from diverse backgrounds and industrial sectors. The perception of engineers wearing dark suits and hard hats is not what STEM is about."*

THE STEM AMBASSADOR PROGRAMME IS A NETWORK OF OVER 30,000 ROLE MODELS FROM INDUSTRY AND RESEARCH ORGANISATIONS. I'm a microbial biochemist by background and, as well as being the Regional Network Lead for London and the South East, I'm proud to be a STEM Ambassador.

FUNDAMENTALLY, IT'S ABOUT ENGAGING WITH YOUNG PEOPLE DIRECTLY, AND MAKING SURE WE OVERCOME SOME OF THE STEREOTYPES AND MYTHS surrounding people who work in construction, engineering, technology, cybersecurity, core sciences, pharmaceuticals, biosciences, etc. What do these people really look like? What do they do? How much do they get paid? I always say we work on behalf of government, which we do, but we're also working on behalf of society and UK Plc. We're giving young people the chance to access a real window of opportunity in the future.

THE JOBS THAT ARE GOING TO EXIST IN THE NEXT 10-20 YEARS' TIME WILL HAVE MOVED ON HUGELY FROM THE JOBS WE TALK ABOUT TODAY OR EVEN 20 YEARS AGO. What the STEM Ambassadors programme does really well is get real people talking about their jobs, which helps to dispel any existing preconceptions young people have of what scientists, engineers and technologists actually do day to day.

STEM AMBASSADORS COME FROM DIVERSE BACKGROUNDS AND INDUSTRIAL SECTORS. The perception of engineers wearing dark suits and hard hats is not what STEM is about. When you think about construction or engineering, you don't realise that there are so many high-value, cutting edge jobs in these fields. People in construction and engineering aren't just shovelling bits of sand around; there are a lot of technical aspects that go into putting a bridge together, building a new aeroplane or developing electronic components, for example; then there are sustainability and environmental issues to consider when looking at different materials; and much, much more.

TEACHERS ARE REALLY KEY TO THIS. Teachers have a huge impact because they're talking to so many students every day. Both teachers and role models such as STEM Ambassadors have a part to play in overcoming barriers to entering into the technology, science and engineering careers of today and the future.

HOW DO WE GET GIRLS TO THINK ABOUT CAREERS IN STEM SECTORS, WHICH ARE SCREAMING OUT FOR MORE DIVERSITY? By showing young people from all backgrounds the variety of STEM career pathways available and getting them thinking about pathways they hadn't previously considered. When girls meet female role models working in engineering, there's often a sudden light bulb moment. They'll say "I like science, but I didn't know I could do that".

FOR ME, THE LETTER "M" IS THE UNDERLYING PRINCIPLE BEHIND ALL OF THE STEM SUBJECTS. The enjoyment and importance of mathematics is something we should strive to.

THE WORD "ENGINEERING" IS QUITE REMARKABLE, ACTUALLY. Amongst our community of STEM Ambassadors, there are engineers involved in chemical engineering, construction, electrical engineering. Engineering is fascinating because there are so many facets to it, and young people understand that when they meet real engineers.

IT'S VERY EASY FOR TEACHERS, SCHOOLS, COLLEGES, COMMUNITY GROUPS AND SCIENCE CLUBS TO FIND A STEM AMBASSADOR. All they need to do is register on the STEM Learning website, www.stem.org.uk, and ask for a volunteer to come to a school, community event or career-related activity.

ABOUT AJAY SHARMAN

"My role is to inspire and enthuse young people in STEM (science, technology, engineering, mathematics) by creating links between those who work with young people and STEM Ambassadors. STEM Ambassadors are volunteers who give up their time to demonstrate the value of STEM subjects in life and careers. If I have businesses telling me that they're getting increased numbers of skilled young people in STEM jobs, that's the kind of impact I want to hear."

ABOUT STEM LEARNING

STEM Learning is the largest provider of education and careers support in STEM. It works with schools, colleges and others working with young people across the UK.

www.stem.org.uk

THERE ARE OVER 30,000 STEM AMBASSADORS, OF WHICH:

43% are women (in London, 50% are women)

60% are under 35

13% are from minority ethnic groups

WHAT DO STEM AMBASSADORS DO?

- CLASSROOM ACTIVITIES TO HELP BRING THE CURRICULUM ALIVE
- PROVIDE CAREERS SUPPORT SUCH AS MOCK INTERVIEWS, CV WORKSHOPS AND SPEED NETWORKING
- SUPPORT STEM CLUB ACTIVITIES
- JUDGE COMPETITIONS AND TAKE PART IN FESTIVALS AND FAIRS
- MENTORING

VICKY STEWART

ASSOCIATE ACOUSTICIAN
ATKINS, PART OF THE SNC-LAVALIN GROUP
STEM AMBASSADOR

"It's my job to investigate sound, and to work with planners and architects to design measures to make places sound better. This can be anything from investigating potential changes in noise from new roads or railways; designing schools to be good learning environments; making sure that people in stations, airports and shopping centres can hear emergency announcements and alarms; and designing the acoustics in cinemas, concert venues and cars, even.

When I was a teenager I was interested in maths, physics and music, and I wanted to work in the music industry, so I went to Salford University to study audio technology.

A graduate in my profession would earn upwards of £25,000, increasing with experience and responsibility.

I love that my job gives me the opportunity to make a difference to people's lives, work with interesting people, and see the projects that I work on come to life."

JAMES STONES

CHARTERED AND EUROPEAN PATENT ATTORNEY
BECK GREENER
STEM AMBASSADOR

"My job involves identifying and helping to secure intellectual property rights for my clients' ideas, and defending their patent rights from attack by others. I also defend my clients' "freedom to operate", which means that I help my clients attack the patent rights of others, thereby clearing the way for my clients to commercialise their ideas. In the main, I draft and file patent applications for inventions, and guide the applications through examination to grant.

The profession is generally well paid. New starters can expect a salary in the region of £32,000 rising to about £55,000 when newly qualified, and to about £70,000 after two years' experience.

What I love most about being a patent attorney is the involvement in the development of an invention: from the original idea, which might simply be on a piece of paper, to the launch of a commercial product into the market."

© Olivia Konert, Doane University

FIND. IDENTIFY. ACT.

SCIENTISTS AT **DOANE UNIVERSITY** HAVE DEVELOPED NANOPRINTED SENSORS THAT CAN IDENTIFY UNKNOWN SUBSTANCES, BUT WHY IS THIS IMPORTANT?

DR ANDREA HOLMES

Professor of Chemistry
Doane University, Nebraska, USA
Field of research: Nanotechnology

RESEARCH PROJECT

DETECHIP®, a small, portable detection chip that can be used by the police, doctors, the military and the general public, even, to identify drugs, pesticides, explosives, microbes that cause bacterial infections, and much, much more.

Imagine these two scenarios:

1) Soldiers come across an unknown substance whilst on patrol. This substance could be an explosive or nerve gas, but they have no way of knowing just by looking at it.

2) Environmental scientists are told that fish are dying in a stream, miles away from their workplace, but they can't tell which pollutant or microbe is causing this without taking samples of the water back to their lab.

Being able to identify unknown substances on the spot and outside of the lab is incredibly important, but, currently, it isn't easy to do this without sending samples to a laboratory for testing. Dr Andrea Holmes and her team have developed a nanoprinted sensor called DETECHIP, which she hopes can be used in all sorts of situations and environments to immediately detect unknown substances.

WHAT IS A NANOPRINTED SENSOR?

Short for 'detection chip', the DETECHIP is made up of coloured inks printed onto a paper-like surface. These coloured inks are called nanoprinted sensors, which work in a similar way to the urine test strips doctors or nurses use to test for infections. When the inks come into contact with a drug or other substance, they change colour. And, by analysing the colour changes, it is possible to identify the substance.

The paper-like surface is almost like a sponge, in that it has tiny pores that soak up the inks or sensors. The inks are called nanoprinted sensors because the miniscule pores are only 1 nanometre in size, and a special printer known as a Dip Pen Nanolithography or DPN printer can place minute or nanosized amounts of ink onto the surface.

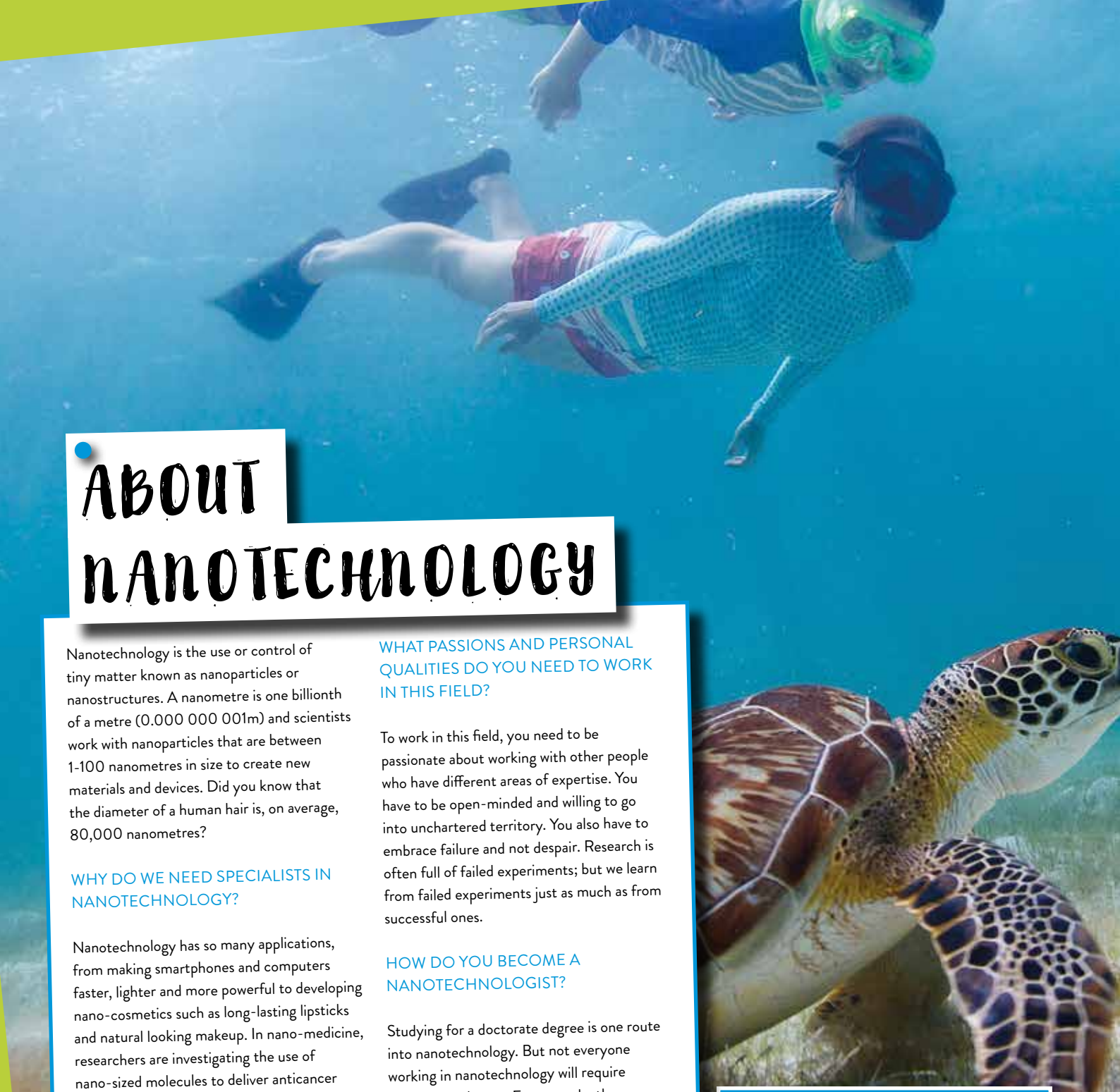
Incredibly, larger nanoprinted sensors can also be printed using a standard ink jet printer available in any office supply retailer. Police officers, for example, might want to use these bigger sensors so that they can test for substances such as cocaine. A larger sensor would enable the policeman or woman to see the colour changes immediately. Nanosized sensors can only been seen under a microscope, but this is very useful when thousands of experiments need to be performed, or if there is only a small amount of the substance to identify.

CAN THE DETECHIP BE USED NOW?

At the moment, DETECHIP can identify over 100 substances, from drugs of abuse to pharmaceutical drugs, pesticides, warfare agents such as nerve gas, and many more, but it isn't being used outside of Andrea's lab – yet! The researchers are developing a smartphone app that can analyse colour changes from a photo.

The next step, then, is to supply people working in the emergency services, such as police officers, with DETECHIP and the smartphone app so that they can detect potentially dangerous substances like explosives. All they would need to do is place a sample on the DETECHIP, take a photo of the colour change, and let the app tell them exactly what the substance is.

The smartphone app analyses colour changes from a photo



ABOUT NANOTECHNOLOGY

Nanotechnology is the use or control of tiny matter known as nanoparticles or nanostructures. A nanometre is one billionth of a metre (0.000 000 001m) and scientists work with nanoparticles that are between 1-100 nanometres in size to create new materials and devices. Did you know that the diameter of a human hair is, on average, 80,000 nanometres?

WHY DO WE NEED SPECIALISTS IN NANOTECHNOLOGY?

Nanotechnology has so many applications, from making smartphones and computers faster, lighter and more powerful to developing nano-cosmetics such as long-lasting lipsticks and natural looking makeup. In nano-medicine, researchers are investigating the use of nano-sized molecules to deliver anticancer drugs directly to the tumour, thereby avoiding damage to nearby healthy cells and tissues.

On the flip side, it is suggested that nanotechnology can be harmful to human health and the environment. For example, sunscreens use silicon-based nanoparticles, and many environmentalists claim that these nanoparticles are toxic to aquatic life. For this very reason, tourists in Mexico have to have a shower to remove sunscreen if they want to swim with giant turtles or in natural water springs.

All in all, nanotechnology has many unanswered questions that need to be addressed by specialists.

WHAT PASSIONS AND PERSONAL QUALITIES DO YOU NEED TO WORK IN THIS FIELD?

To work in this field, you need to be passionate about working with other people who have different areas of expertise. You have to be open-minded and willing to go into unchartered territory. You also have to embrace failure and not despair. Research is often full of failed experiments; but we learn from failed experiments just as much as from successful ones.

HOW DO YOU BECOME A NANOTECHNOLOGIST?

Studying for a doctorate degree is one route into nanotechnology. But not everyone working in nanotechnology will require a doctorate degree. For example, the International Association of Nanotechnology, in partnership with the California Institute of Nanotechnology and Clean Tech Institute, offer training programmes and apprenticeships.

The Los Alamos National Laboratory, which houses the Center for Integrated Nanotechnologies, is one of the most famous and highly respected labs in the world. Los Alamos offers undergraduate internship programmes and open positions for post-baccalaureates. The salary depends on the scientist's level of expertise. For example, the average salary for a Level 5 scientist is $159,000 per year.

OPPORTUNITIES IN NANOTECHNOLOGY

- THE INTERNATIONAL ASSOCIATION OF NANOTECHNOLOGY OFFERS TRAINING PROGRAMMES AND APPRENTICESHIPS
- LOS ALAMOS NATIONAL LABORATORY, USA, OFFERS INTERNSHIPS AND OTHER CAREER OPTIONS
- LEVEL 5 NANOTECHNOLOGISTS CAN EXPECT TO EARN AROUND $150,000 A YEAR

ASK DR ANDREA HOLMES

WHAT DID YOU WANT TO BE WHEN YOU WERE YOUNGER?

I always wanted to be a teacher. As a kid, when I role-played with my little sister, I insisted on being the teacher, and she had to be the student! After a while, she didn't like that anymore because I kept reprimanding her for not doing her homework! I realised then that I had to change my teaching style and explore new ways of getting her excited about "my class". From an early age, I had this innate feeling that I would be a great teacher and mentor.

As I grew older, and during adulthood, I connected best with students between 18-25 years of age, which is why I decided to pursue an academic career at a university.

WHO OR WHAT INSPIRED YOU TO STUDY CHEMISTRY?

I was definitely not inspired by my high school grades. In fact, I hardly passed high school; I was almost kicked out for disorderly conduct and received mostly C or D grades in my courses. I was a rebel teenager with little desire to do anything in STEM.

At one point, however, I realised that I needed to take care of myself and make a living. So, I decided to become an X-ray technician. After a while, I got bored with that, and I didn't have enough patience to work with sick patients. I decided to attend college to get a Bachelor of Science degree. It was during my undergraduate education, that I became hooked on chemistry and nanotechnology.

During my undergraduate degree, I struggled in chemistry, and even though I studied and studied, I still wasn't very good at it. But I wanted to conquer this incredible mountain, and that kept me on top of my game. Since then, I have never been bored again. I still find nanotechnology fascinating even though it can be hard to understand. Sometimes, I'm surprised by significant contributions I have made to nanotechnology.

YOU STUDIED BIOLOGY, CHEMISTRY AND MATHS AT UNIVERSITY. IS THIS A 'STANDARD' ROUTE TO WORKING IN NANOTECHNOLOGY?

To be a professor at a university you have to have a doctorate. A doctoral degree involves completing independent research and a thesis, a long essay or dissertation that supports the research. During my doctoral education, I took organic chemistry courses but mostly conducted organic chemistry research for my thesis. There is no standard route for working in the field of nanotechnology. This field is so interdisciplinary [involving many subjects and areas of knowledge], that nanotechnology researchers might have backgrounds in physics, engineering, biology, materials science or computation, for example.

IF YOU COULD GO BACK IN TIME WHAT ADVICE WOULD YOU GIVE YOURSELF WHEN YOU WERE STARTING OUT ON YOUR CAREER PATH?

I would tell myself not to be intimidated and ask questions. When I started in graduate school, I was very insecure about my qualifications and abilities, and I was really shy when I went to conferences or symposia where scientific research was presented. I felt that all these famous professors and researchers would think my questions were stupid. Now, having been in this field for so long, I realise this was a big mistake. I should have told myself back then that the only stupid question is the one not asked!

> *"I was definitely not inspired by my high school grades. I hardly passed high school, and received mostly C or D grades in my courses."*

DO YOU HAVE A TOP TIP FOR YOUNG PEOPLE HOPING TO FOLLOW IN YOUR FOOTSTEPS?

Many young people don't know about careers that exist in chemistry or nanotechnology. My students usually want to become physicians [doctors] or to work in other, similar healthcare professions. I like telling my students that they have enough years in their lifetime to pursue at least three professions. They don't have to decide on a career for life. In fact, they have enough time to explore and work in several professions until they find the right fit.

Dr Andrea Holmes also teaches at Doane University

ANDREA'S FIVE TOP TIPS FOR STUDENTS

1. NO BARRIERS! EXPLORE, EXPLORE, EXPLORE!
2. OPEN YOUR MIND! THERE IS SO MUCH OUT THERE
3. TRY IT ALL UNTIL YOU FIND WHAT'S RIGHT FOR YOU
4. DO NOT BE AFRAID AND ASK QUESTIONS
5. DO NOT BE DISCOURAGED BY BAD GRADES. GRADES DO NOT REFLECT YOUR CAPABILITIES

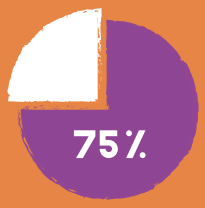
THE FUTURE IS BRIGHT WITH OPTICS

MODERN SOCIETY IS INCREASINGLY RELIANT ON DEVICES THAT RUN ON LIGHT, BUT THERE'S A GLOBAL SHORTAGE OF OPTICS AND PHOTONICS TECHNICIANS. **DR ALEXIS VOGT** OF **MONROE COMMUNITY COLLEGE** HAS CREATED THE 'OPT-IN!' PROGRAMME, THE AIM OF WHICH IS TO DEVELOP MUCH-NEEDED TALENT IN THIS IMPORTANT FIELD

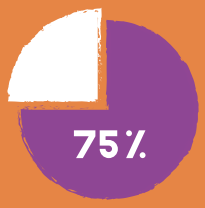
WHAT'S THE ISSUE?

Thanks to optics and photonics, new technologies are advancing at what seems like breakneck speed. High speed internet, barcodes, laser tattoo removal, pace-makers, video surveillance systems, video streaming (and much, much more) all rely on photonics; and the technologies of the future will be even more reliant on these light-centric breakthroughs: solar power, driverless cars, laser surgery…

The optics and photonics industries are growing by more than 3% per year. And 20% of experienced technicians and engineers are approaching retirement, meaning there are more jobs available in the industry than ever before. Unfortunately, there aren't enough skilled STEM graduates to fill these vacancies. For example:



of Upstate New York optics technician job openings go unfilled annually



of small and mid-sized German companies report that their shortage of skilled workers impairs their ability to innovate

Whether it's telecommunications, medical imaging or cancer research, the vital technologies of today are reliant on the science of light: optics and photonics; and yet there's a serious shortage of experts with the appropriate skills to work in these areas. Consequently, there is a push to find passionate students of STEM, and to encourage them to take up careers in optics and photonics. But doing so is not just about filling a void. Optics technicians can make a real difference. They are at the forefront of innovation and design in many areas such as medicine, national security, manufacturing and renewable energy.

In recognition of the wonderful opportunities available in optics and photonics, Dr Alexis Vogt of Monroe Community College (MCC) created 'OPT-IN!' – a programme designed to strengthen the optics and photonics workforce to fill high-skilled, high-demand positions, and provide students with employment opportunities in regional industries.

WHAT DOES OPT-IN! DO DIFFERENTLY?

The shortage of optics and photonics experts has lot to do with the lack of suitable education and training programmes. While MCC had been running a two-year degree programme in optics since 1971, Alexis wanted to boost the intake of students into the programme with an updated curriculum, a variety of course delivery models and state-of-the-art laboratory resources. She also wanted to provide professional development, strengthen industry partnerships and broaden community awareness of educational and employment opportunities in the fields of optics and photonics.

The OPT-IN! programme aims to connect more high school and college students with industry — and to produce the skilled workforce needed to keep up with demands. Another noteworthy difference is that OPT-IN! offers internships and expands outreach efforts to underrepresented populations in the industry, including women and minority groups.

HOW DOES OPT-IN! SUPPORT STUDENTS FROM UNDERREPRESENTED GROUPS?

OPT-IN! has several recruitment, retention and outreach initiatives to build awareness of the programme, including the development of a portable Optics Road Show and other public presentations. Presentations have been developed for both general audiences and audiences from historically underrepresented populations such as women, African Americans, Latinos, and those from low income backgrounds.

WHAT HAS OPT-IN! ALREADY ACHIEVED?

As a testament to the effectiveness of OPT-IN! and its recruitment strategies, 17 students graduated from MCC's optics programme in May 2018. That is, in fact, a 325% increase from May 2016 – before OPT-IN! was set up.

Another notable aspect of OPT-IN! is the partnerships it has fostered with local high schools. Interestingly, OPT-IN! has helped teachers to start teaching MCC optics courses

© Alexis Vogt. four sets of lenses being polished.

DR ALEXIS VOGT

Associate Professor of Optics
Monroe Community College
State University of New York, USA

FIELD OF RESEARCH

Optics and its various real-world applications

RESEARCH PROJECT

OPT-IN! aims to connect more high school and college students to career opportunities in the field of photonics and optics, thus addressing the shortage of professionals in associated industries.

FUNDER

National Science Foundation
Grant No. 1700617

in high schools. Students who successfully complete the school-based course receive official MCC credit. Nine high schools are currently participating in the programme and over 200 high school students are enrolled. This is an increase of 260% from 2013.

WHAT ARE GRADUATES SAYING ABOUT OPT-IN!?

Consider the following comments from students, who have been trained up and placed in industry by OPT-IN!:

"Hello Professor Vogt. I am happy to say I got the job with OptiPro. I will be an Advanced Process Development Lab Technician. I start on July 9th. I really appreciate everything you taught me and the position you put me in to succeed was great. Hope to see you around in the future in the well-knit optics community!" – **Justin Arrajj, working at OptiPro.**

"Professor Vogt, the end of the semester came fast, and I did not get a chance to properly thank you for all your help, support, guidance and knowledge shared throughout my time in the optics program. I truly believe the time spent in the program was well worth it and that it was the push I needed in the right direction for my future. As a job update, I did accept a full-time position at RPO as an Optical Technician." – **Salaahuddin Karim, working at RPO.**

"Hi Professor Vogt. I just wanted to thank you for all you did during my time at MCC. Your passion for optics helped develop my own personal interest in the field and I'm proud to say that I just got accepted into the University of Arizona to continue my education!" – **Umut Kocak received a two-year Associate Degree in Optics from MCC and then transferred to the University of Arizona to complete his four-year Bachelor of Science in Optics.**

Clearly, OPT-IN! is making a difference – creating an effective pipeline between high schools, colleges and the optics industry. And, with more graduates entering this rapidly growing and diversifying industry, the programme's future accomplishments will have a global impact.

As Alexis reiterates, "Optics and photonics is one of the most amazing careers in the world and not enough people know it exists as a discipline of study!" She is doing as much as she can to change that.

© Alexis Vogt. Lenses being polished

© Alexis Vogt. Inspecting lenses

© Monroe Community College. Student inspecting a lens during the manufacturing process

ABOUT OPTICS AND PHOTONICS

Optics is the field of science and engineering that deals with the origin, movement and detection of light. As for photonics, it's a term to describe the application of optics to perform functions that traditionally fall within the domain of electronics, such as telecommunications and information processing.

To illustrate the difference between the two, imagine you're buying vegetables at a grocery store. You can buy just broccoli, or you can buy an entire assortment of vegetables – broccoli, corn, spinach, peas, squash and so on. The field of photonics could be likened to the broccoli, while all the vegetables collectively represent optics. In other words, photonics is a branch of optics.

WHY DO WE NEED PHOTONICS AND OPTICS EXPERTS?

Light is used in devices such as computers, smartphones and medical instruments. It can make these faster, smaller and more energy efficient. Wouldn't we all want our devices faster, smaller and more energy efficient? Light can even be used to manoeuvre DNA and other types of nanoparticles to research cures for cancer. So, we need to get the word out that optics and photonics is an exciting and productive career path.

WHAT DOES AN OPTICS AND PHOTONICS TECHNICIAN DO?

An optics and photonics technician works with scientists and engineers in research, development, design, manufacturing and quality control. Optics and photonics technicians hold the critical roles of manufacturing optics and performing testing and evaluation of optical components and systems. Optics companies cannot ship products out their doors without optics and photonics technicians.

WHAT SKILLS AND PASSIONS DO YOU NEED TO BE AN OPTICS AND PHOTONICS TECHNICIAN?

Optics and photonics technicians work extensively with their hands to manufacture and measure optical components and systems. Research has shown that musicians, gamers, chefs, artists and mechanics make excellent optics and photonics technicians because of their demonstrated hand-eye coordination.

WHAT OTHER CAREER OPPORTUNITIES ARE THERE IN THIS FIELD?

An Associate Degree in Optics from MCC opens the doors to your career. Many go on to directly work in the optics industry for a company around the world. Some MCC graduates have, with their associate degree, advanced through their career to become CEOs of optics companies. Graduates may also find positions in:

- Academic institutions
- Government laboratories
- Technical sales
- Law firms
- Entertainment
- Business management
- Politics and advisory boards

Other graduates spend two years at MCC and then transfer to a four-year university for two additional years to pursue a Bachelor of Science in Optics or Imaging Science.

WHAT'S SO GREAT ABOUT WORKING IN OPTICS AND PHOTONICS?

Working in optics and photonics means you are working with cutting-edge technology that enhances people's lives.

> *"Optics and photonics is one of the most amazing careers in the world and not enough people know it exists as a discipline of study!"*

OPPORTUNITIES IN OPTICS AND PHOTONICS

- Corning Incorporated launched a Technician Pipeline Program, which includes a salary of $25,000/year for 8 hours of work per week, a two-year scholarship to earn a Degree in Optical Systems Technology at MCC, and conversion to a full-time technician role at Corning Incorporated upon completion of the programme
- Other companies such as Optimax, OptiPro, JML Optical, Schott and APOMA offer optics-related apprenticeships
- Skilled optics and photonics technicians can make over $100,000 with a two-year Associate in Applied Science Degree from Monroe Community College

ASK DR ALEXIS VOGT

WHAT DID YOU WANT TO BE WHEN YOU WERE YOUNGER?

At a young age I said I wanted to be a kindergarten teacher. Apparently, I had the teaching part right, but the subject matter wrong. Instead of teaching students the fundamentals of reading, I'm teaching students how to read highly technical read-outs and data!

WHO OR WHAT INSPIRED YOU TO FOLLOW A CAREER IN OPTICS AND PHOTONICS?

The origin of my career in optics can be traced to my freshman year at the University of Rochester. Heeding the advice of friends who spoke highly of a professor who taught an introductory course in optics, I signed up for his class. I took the Intro to Optics course and the professor, Turan Erdogan, was fantastic. His ability to distil and convey complex optics principles in a compelling and engaging way was remarkable. He's a brilliant leader, accomplished businessman, family-focused and faith-filled man; he has inspired and motivated me since my optics career began.

WHICH SUBJECTS DID YOU STUDY AT UNIVERSITY?

My undergraduate degree is in optics from the Institute of Optics at the University of Rochester. I also completed my PhD in optics at the University of Rochester.

WHAT ADVICE WOULD YOU GIVE TO SOMEONE WHO IS STARTING OUT ON THEIR CAREER PATH?

My advice to someone starting out is to work hard, ask questions and always treat everyone with respect. The only limit to what you can do is your own ambition.

© Alexis Vogt. Student polishing lenses

© Monroe Community College. Student polishing lenses

© Monroe Community College. Alexis helping a student align a laser

CAN THIS RESEARCH TEAM REVERSE CLIMATE CHANGE?

GLOBAL WARMING, CLIMATE CHANGE, THE GREENHOUSE EFFECT, INCREASING CARBON DIOXIDE LEVELS: WE HAVE ALL HEARD OF THESE WORRYING EVENTS, BUT WHAT CAN WE DO ABOUT THEM? **PROFESSOR CHRIS JONES** AND HIS RESEARCH TEAM HAVE BEEN WORKING ON A NEW METHOD TO REMOVE CARBON DIOXIDE FROM THE AIR WE BREATHE – POTENTIALLY **REVERSING CLIMATE CHANGE**

IMAGINE THIS

Global temperatures are increasing; polar ice caps are melting; sea levels are rising: our planet is in jeopardy, and much of this is a result of rising levels of CO_2. Cars, planes, food, housing materials, deforestation – our very lifestyles – are resulting in soaring carbon dioxide (CO_2) levels that are wreaking havoc on the environment.

We need to reduce CO_2 levels and FAST.

WHAT CAN WE DO?

- Trees and plants absorb CO_2, so reforestation would be a good place to start
- Changing to renewable energy sources would reduce the amount of fossil fuel combustion and therefore the amount of CO_2 released
- Simple lifestyle changes such as walking or cycling instead of taking the car would also help reduce CO_2

But reducing the amount of CO_2 we produce isn't enough; we need to remove the CO_2 that is already there – a process known as negative emissions. Could a chemical engineer develop a product that could remove the carbon dioxide from the air?

Climate change is a term that describes both the increase in average global temperature (global warming) and its effects on our planet; for example, on our weather systems. According to the Met Office, the average global surface temperature has increased by about 1 °C since the 1850s. The Met Office also reports that the last three decades have been successively warmer. The Intergovernmental Panel on Climate Change (IPCC) has concluded that "It is extremely likely that human influence has been the dominant cause of the observed warming since the mid-20th century." The emission of greenhouse gases, such as carbon dioxide (CO_2) from burning fossil fuels, is the main culprit in climate change. The IPCC also concludes that if we can cap the level of climate change at 1.5°C, then we may be able to avoid some of the most catastrophic effects of the climate crisis. So, we need ways to reduce CO_2 production or even to remove it from the atmosphere.

WHAT IS PROF CHRIS JONES DOING TO TACKLE CLIMATE CHANGE?

Chris is a chemical engineer from the Georgia Institute of Technology, USA. As a chemical engineer, he takes chemicals and raw materials and develops them into useful products for society. In one ambitious project, he is using amine-oxide hybrid materials to create a device that will remove this CO_2 from the ambient air, i.e. the air we breathe. This process is called direct air capture (DAC).

Carbon capture technologies that are able to "capture" CO_2 already exist, but these tend to reduce CO_2 emissions locally. Capturing carbon within the flue of a power station is an example of a localised carbon capture technology. DAC, on the other hand, is a type of negative emissions technology (NET). This means that it extracts CO_2 that has been released from a multitude of sources over a long period of time, including from cars and aeroplanes as well as power plants and factories.

Negative emissions technology is therefore able to reduce the amount of CO_2 in the air and has the potential to reverse climate change!

HOW DOES CHRIS' DAC TECHNOLOGY WORK, EXACTLY?

In order to remove the dilute amounts of CO_2 in the air, a material has to be able to bind to the gas very strongly. Chris' amine-oxide material binds to CO_2 through acid-base interactions. You'll have learnt about acids and bases at school: acids, such as citric acid found in lemons, have a low pH; whilst bases, such as sodium hydroxide found in cleaning products, have a high pH. Alkali is a term for bases that are soluble in water.

CO_2 is weakly acidic and the amine groups ($-NH_2$) are basic. When CO_2 passes by the amine groups, an interaction occurs, and the carbon is caught or "captured" by the amines (see "What's the chemistry?").

To engineer this chemical reaction into a useful tool, Chris' group used an oxide support, such as aluminium oxide, built into a monolithic, honeycomb structure, which has a large surface

area. The amines were introduced in long chains or polymers with many side chains, and were attached to this honeycomb.

The next development was to incorporate an air-blowing machine (imagine a leaf blower) into the device. This blows large quantities of air through the honeycomb structure. As the air passes through, the amine materials "grab" the CO_2, removing it from the air. The remaining air blows straight out the other end!

Chemical engineers often work closely with industry, and Chris is no exception. He is collaborating with a start-up company called Global Thermostat. "Global Thermostat believe their technology, if successfully deployed at scale, could act as a global temperature controller for the Earth" he says. "Take out more CO_2 to cool; slow CO_2 removal to warm!"

WHAT'S THE CHEMISTRY?

Let's describe acids and bases even more scientifically. There are three theories of acids and bases: the Bronsted-Lowry, Arrhenius and Lewis theories.

According to the Bronsted-Lowry definition, an acid is a proton donor that can donate a positive ion, usually a hydrogen ion (H^+). A base is a proton acceptor that can receive a positive ion, again, usually H^+. These charge differences enable the acid and base to interact to make a neutral product.

The Arrhenius theory describes acids as substances that produce hydrogen ions in solution, and bases as substances that produce hydroxide ions in solution. When the hydrogen and hydroxide ions interact, they produce water, a neutral product.

Finally, Lewis theory gives the broadest definition, describing acids as electron pair acceptors and bases as electron pair donors.

In Chris' device, the acid is carbon dioxide and the base is the amine group. $CO_2 + 2\ R\text{-}NH_2 \text{ ---> } R\text{-}NH_3^+ + R\text{-}NHCOO^-$, where R represents a hydrocarbon chain.

When carbon dioxide and amine groups interact, a chemical reaction takes place, creating strong bonds. The equation above shows the formation of an alkylammonium carbamate, which is the key product formed from reactions of a solid-supported amine and CO_2. The amines act as bases, with one amine donating electrons (Lewis theory) to the acidic molecule CO_2, forming a covalent N-C bond. A second amine group removes a hydrogen ion from this product, producing an ammonium $R\text{-}NH_3^+$ group. The final product is a cation-anion pair, the alkylammonium carbamate.

PROF CHRIS JONES

Professor of Chemical and Biomolecular Engineering, the Georgia Institute of Technology , USA

FIELD OF RESEARCH

Chemical and Biomolecular Engineering. Specialty: Catalysis and Carbon Capture

RESEARCH PROJECT

Chris' research group is developing materials that extract carbon dioxide directly from the air in a process called "direct air capture". This is one of the few methods that could reverse climate change.

FUNDERS

US Federal Government: National Science Foundation, Department of Energy; Industry: The Dow Chemical Company, Global Thermostat LLC

WHAT HAPPENS TO THE CARBON?

When the amine-oxide material is sufficiently loaded with CO_2, the device is heated up, which causes the gas to "fall off" the material. The resulting concentrated CO_2 product must then be stored – usually by compressing it to high pressure and depositing it underground – hopefully for hundreds of years. Alternatively, it can be sold as a commodity: CO_2 has various industrial uses, from food to oil and chemicals. However, to be classed as a negative emissions technology, the carbon must be packed away somewhere so that it can't escape back into the atmosphere.

WHEN WILL DAC BE READY TO USE?

"Until recently, there hasn't been a strong market for NETs and DAC," says Chris. "And therefore fewer ways for companies to monetise DAC technologies. While the amine-oxide hybrid materials we work with are relatively easy to make, they're not being produced at commercial scale yet. As the market develops, I anticipate an array of companies, both established and start-ups, will be poised to manufacture such materials. We're working with several of them today."

The first commercial DAC unit on the market was produced by a company called Climeworks and is in use in Switzerland. Hopefully, this is the start of many.

However, while large scale use of DAC could negate the effects of our fossil fuel-burning lifestyles, it's vital that we move to renewable and more sustainable energy sources. What's exciting is that Chris' technology could help give us more time: "This would allow a slower transition to a renewable, energy-rich future, offering less economic disruption and loss of jobs associated with fossil energy," he says. "It could be both a climate and market stabiliser."

ABOUT CHEMICAL ENGINEERING

If you enjoy solving problems, perhaps chemical engineering is for you. Using knowledge of science, computing and maths, chemical engineers turn raw materials into useful products, overcome hurdles and develop new methods. They bridge the gap between research and manufacturing.

Chemical engineers design, modify and improve the way we produce a vast array of everyday goods: face creams, chocolate, fuels, medicines, sustainable energy, waste treatment, the development of stem cell therapies. Wherever your interest lies, there is a niche for you.

Chemical engineers often work in large teams of people from various backgrounds such as mechanical, electrical and other types of engineers, as well as with scientists, business professionals and policymakers. "Chemical engineering is a powerful field that can open doors to a variety of careers," says Chris.

HOW DO YOU BECOME A CHEMICAL ENGINEER?

Careers in chemical engineering require an undergraduate degree, either a bachelor's degree (BEng), which takes 3-4 years and gives a solid understanding of the principles of chemical engineering, or a Master's degree (MEng), which typically lasts a year longer, providing a more extensive knowledge base, usually in a specific area of chemical engineering. Employers look for candidates with relevant work experience, so when applying for university courses, it's sensible to select ones with an internship or industrial placement scheme.

During their early career, many chemical engineers aim to achieve chartered status – a qualification that demonstrates experience and expertise.

Graduates can work a wide range of industries, including:

- Food and beverages
- Biotechnology
- Consumer products (detergents, batteries, automobile, etc.)
- Energy – oil / gas as well as renewable
- Polymers / plastics
- Chemicals
- Business management and consulting
- Pharmaceuticals
- Water
- Numerous graduate schools (medical, dentistry, pharmacy, law, business, etc.).

Graduate starting salaries for chemical engineers are high and are in the region of $68,520 in the US. The average salary for a chemical engineer is $112,430, although this varies according to location and sector.

Teenlife promote various engineering summer schools in the US – check them out!

CHRIS' TOP TIPS

Many STEM students think that only maths and science subjects are important for their career. Although these are clearly vital, other skills are also important to be a successful chemical engineer:

- Communication skills are what differentiates a good engineer from a great engineer. The most successful chemical engineers have excellent language skills and are effective communicators
- It is important to be well-rounded. Engineering is about applying your skills to improve humanity, so being comfortable with social sciences like public policy, economics and sociology is helpful
- Trust your gut and choose subject areas that you enjoy
- Be business savvy – many chemical engineers either work in industry, have collaborations with industry, or create start-ups

ASK PROF CHRIS JONES

WHY DID YOU CHOOSE TO STUDY CHEMICAL ENGINEERING?

Through middle school, I had little knowledge of what types of careers were available beyond the obvious ones (doctor, lawyer, teacher, police, etc.), but I knew I liked science, based on success in science subjects and positive feedback from teachers.

In high school, I took my first chemistry course and found it was easy to learn, so I took additional chemistry courses. My chemistry teacher encouraged me further, but also mentioned that if I was good at maths, I should consider being a chemical engineer because he believed there were more job opportunities for a BS chemical engineer than a BS chemist.

I took both chemistry and chemical engineering courses in my first two years of university and found I really liked chemical engineering, so decided to take that route. I chose this major primarily because I felt I was good at it and therefore enjoyed it, more so than with any specific career path in mind.

IS THERE ANYTHING THAT YOU WOULD DO DIFFERENTLY IF YOU COULD GO BACK IN TIME TO YOUR PRIMARY AND SECONDARY SCHOOL YEARS?

Yes, I would study a foreign language at an early enough age to become fluent. Because English is the language of science and the primary international language, relatively few young people from English-speaking countries become fluent in a second language. Do it! It opens doors culturally, and the earlier you start, the easier it is to become fluent.

ARE THERE ANY STEREOTYPES ABOUT SCIENTISTS AND ENGINEERS THAT YOU WISH TO BREAK?

Many people envision scientists and engineers as people who work in isolation, in a lab and away from people. In reality, science has given me a great balance between social activities and alone time. I love studying a subject deeply on my own. When I was younger, I loved working on my own project in the lab alone.

But the global research community in carbon capture and catalysis, my two fields, is well-connected and close-knit. Through international research conferences, I've developed close friends in 40+ countries around the world. Because scientists and engineers all speak a common language (the scientific method as applied to their specialty subject area), cultural barriers are easily broken down, and friendships are readily made, allowing for a strong social component to the job.

ARE YOU AN ECO-WARRIER AT HOME AS WELL AS AT WORK?

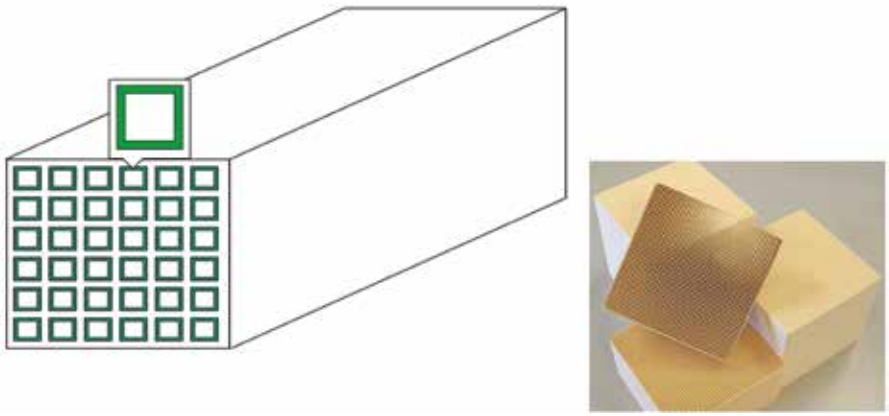
No, not as much as I should be, and this is a source of constant internal struggle for me. I feel strongly about climate change, conservation and energy efficiency, but I also travel a lot for my job (I fly 50-75k miles per year), which has a huge carbon footprint. I also like to drive my car on racetracks.

I grew up in Detroit, the 'Motor City', so automobiles are in my blood. Racing is not often viewed as a model activity for energy conservation. But these activities bring me joy, so my research is focused on developing technologies that will allow my travel and racing to be eco-friendly. Check out Formula E racing!

WHAT DO YOU LIKE TO DO IN YOUR FREE TIME?

I love my job, my research, and interacting with my students, so I spend a lot of my free time at work. But I also love to travel (40+ countries to date, and all five major continents covered) and I watch a lot of ice hockey (Detroit Red Wings) and auto racing (Formula 1, Formula E).

> *"Many people envision scientists and engineers as people who work in isolation, in a lab and away from people. In reality, science has given me a great balance between social activities and alone time."*



A honeycomb, monolithic air/solid contactor is lined with CO_2-absorbing amine materials (green).

http://appliedceramics.com/product-lines/versagrid-ceramic-honeycomb/

WHY DO SOME GLACIERS MELT FASTER THAN OTHERS?

AS THE CLIMATE WARMS, GLACIERS – THE BIGGEST RESERVOIR OF FRESH WATER ON THE PLANET – ARE MELTING. BUT SOME ARE MELTING FASTER THAN OTHERS. **DR ELLYN ENDERLIN**, ASSISTANT PROFESSOR OF GEOPHYSICS AT **BOISE STATE UNIVERSITY**, IS INVESTIGATING GLACIER MELT TO UNDERSTAND HOW IT MIGHT INFLUENCE THE EARTH'S SYSTEM

WHAT WILL HAPPEN IF THE POLAR ICE CAPS MELT?

Melting of the polar ice caps causes:

- Increases in sea level
- Changes to ocean circulation – the addition of cold and fresh glacier melt water influences the flow of ocean water in polar regions, potentially altering global ocean circulation and climate
- Changes to global climate – as the ice sheets melt, the amount of solar radiation reflected by the Earth decreases, leading to more global warming

It's difficult to predict how these changes will progress in the long term, and what effects they will have on our planet.

However, it's likely that these outcomes will have detrimental effects on:

- Ocean ecosystems and their productivity (fisheries)
- Oxygen levels in the ocean
- Carbon dioxide uptake by the ocean
- Climate change

Predicting when, where and why glaciers melt will help to determine the severity of these effects and help us to plan for the future.

Not all glaciers are created equal.

Although all glaciers are sensitive to climate change – on average, approximately 50 billion tonnes of ice from Alaskan glaciers have been lost each year in recent years – the response of individual glaciers to changes in temperature varies a lot.

Understanding why some glaciers are more sensitive than others is important, because it could lead to more accurate predictions of how glaciers will change in the future.

Dr Ellyn Enderlin, Assistant Professor of Geophysics at Boise State University in Idaho, attributes the different responses of glaciers to climate change to variations in their shape. "Their shape influences how a glacier interacts with the underlying land and the ocean," she explains. Her research explores how and why glaciers melt, and what happens to the surrounding environment when glacier melt changes.

WHAT IS A GLACIER?

Glaciers are huge bodies of ice that form from fallen snow over many years. They can form anywhere where there is lots of regular snow, such as Alaska, Greenland and Iceland, and where there isn't much snow but temperatures stay cold year-round, like Antarctica. When enough snow accumulates, its weight causes it to compact until it eventually turns into ice. When they get big enough, the glaciers will flow downhill to areas where the snow and ice will melt.

Some glaciers eventually flow into the oceans, where icebergs form. Icebergs are the huge pieces of ice that break off from glaciers to float freely in the ocean. They can float on the ocean because water is less dense when it is in solid form.

There are many types of glaciers, ranging from small cirque glaciers at high elevations in the mountains to huge ice streams that drain the massive ice sheets covering Antarctica and Greenland. The problem is, they are all shrinking because of climate change.

WHAT HAPPENS WHEN GLACIERS MELT?

When glaciers melt, sea level rises, the temperature and saltiness of polar oceans lower, and the amount of sunlight absorbed by the Earth increases, all of which could threaten the ability of humans and ecosystems to adapt to climate change.

When glaciers rest on land, melt water runs off them and flows to the oceans, contributing to sea level rise. Some of this melt water will also make its way through the glacier to the bottom, underneath the glacier. This water acts as a lubricant on the ground, allowing the glacier to flow faster downhill than if it rested on a dry surface. This means that the glacier flows faster towards the lower, and consequently warmer, elevation regions where it can melt faster. For glaciers that flow into the ocean, an increase in the speed of their flow also contributes to sea level rise because it means more ice is moving from the land to the ocean.

Interestingly, when ice flows over land and into the ocean, it causes the sea level to rise, but

when floating icebergs melt there is no change in sea level. How does this make sense? If you have a glass of water almost full to the top and you add a bunch of ice cubes to it, the glass will overflow because you've added more water to it (in solid form) than it can hold. But if the glass stays perfectly full afterwards and you let the floating ice cubes melt, no more water will overflow because the water displaces the same volume whether it is solid or melted. Although melting icebergs don't influence sea level, the addition of cold and fresh water can change the temperature of the ocean and the air above it, and this can influence ecosystems and climate.

HOW DOES ELLYN MEASURE GLACIER CHANGE?

Scientists like Ellyn measure changes in the size of glaciers and their flow using GPS trackers and satellite images. These two methods have different uses. GPS provides exceptional detail about glaciers' thickness and flow over short time periods. Satellite images are used to measure changes in glaciers' length, thickness and flow over very large areas and long periods of time. Mapping glacier flow using satellite images is known as feature tracking. "It's like watching a boat drift along in a river. You can figure out the flow of the river by measuring how much that boat moves over time," says Ellyn.

Ellyn's lab uses a range of computer programs to analyse the data captured, such as how quickly a glacier moves and where it goes: "I use these data to measure changes in iceberg production over time and explore how the forces that control ice flow respond to changes in temperatures of the air and ocean."

HOW DOES GLACIER MELT WATER AFFECT OCEAN CURRENTS?

The influx of cold, fresh water into the ocean can have a major impact on what is called the "ocean conveyor belt". The ocean currents carry warm water from the tropics towards the poles and when it gets there, heat is released into the atmosphere and the water is cooled. In fact, it cools so much that sea ice begins to form. The salt in the water doesn't freeze with the sea ice, however, which means that it remains in the unfrozen ocean water, making it even saltier.

At the poles, the water is colder and saltier, and therefore denser. This cold, salty water sinks to the bottom of the ocean and works its way south – just like a conveyor belt! "It's this conveyer belt that makes Europe fairly warm despite its high latitude." says Ellyn "If enough melt water from glaciers (and icebergs) is added to the North Atlantic Ocean, this conveyer belt could slow down, leading to colder temperatures in the Northern Hemisphere, in particular, and warmer temperatures near the Equator."

HOW WILL THIS INFORMATION HELP TO PROTECT THE ENVIRONMENT FOR FUTURE GENERATIONS?

Ellyn and her colleagues aim to understand and predict the speed at which glaciers are melting, and the effect this will have on the ocean conveyor belt. Measuring ice flow will help scientists understand how quickly glaciers are melting, why some glaciers are more sensitive to climate change, and the impact that shrinking glaciers have on the ocean and climate.

DR ELLYN ENDERLIN

Boise State University, USA

FIELD OF RESEARCH

Geophysics, Glaciology, Remote Sensing, Climate Change

RESEARCH PROJECT

Ellyn researches glaciers' response to global temperature changes. She also investigates how glacier melting affects the ocean and is predicting their future impact. She hopes more accurate predictions will encourage more action on climate change.

FUNDERS

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

Ellyn hopes findings like hers will encourage people to take action to curb greenhouse gas emissions. She says uncertainty about how the future will look under climate change decreases individual's motivation to change their behaviour because they don't fully appreciate the long-term risks.

As Ellyn concludes: "Glaciers are sensitive to climate change as a whole, but their responses to climate change differ. We need to know why in order to accurately predict how they'll melt in the future. More accurate predictions of glacier melt and its associated impacts should motivate more action to reduce greenhouse gas emissions."

ABOUT GEOSCIENCE AND GLACIOLOGY

Geoscience is the study of the Earth, its composition and the physical, biological and chemical processes that shape it. It is a big scientific field and can include the study of volcanoes, earthquakes, rivers, oceans, glaciers and more.

The study of glaciers (glaciology) is a field in itself and incorporates geology, geography, maths, physics and chemistry. Geoscientists use lots of different methods to research Earth's interactions, including hands-on field work, analysing samples in the lab, and modelling processes using computers.

Ellyn is passionate about glaciers and geoscience. We ask her why this field makes for an awesome career.

WHY SHOULD YOUNG PEOPLE STUDY GEOSCIENCE?

To me, geoscience is awesome because it incorporates so many other scientific fields to better understand Earth processes. If you're passionate about chemistry, you can study changes in the Earth's atmosphere or investigate the composition of rocks to learn about volcanoes. If you're interested in biology, you can study coral bleaching. Or, if you're a fan of physics, you can measure glacier change (my favourite!), or explore the structure of the Earth beneath our feet. There are so many things that you can do that will advance our understanding of the planet.

APART FROM RESEARCH, WHAT OTHER CAREER OPTIONS ARE AVAILABLE WITH A DEGREE IN GEOSCIENCE?

I know quite a few people that have become environmental consultants, exploring water contamination or wetland management, for example. The increasing use of satellite data has also led to a boom in jobs for people with remote sensing skills. I have students interested in jobs with insurance companies because these companies want to assess the impacts of natural disasters using satellite images. There has also been an increase in scientific writing jobs, with more companies looking for people who have a firm understanding of science and can write well-informed articles.

YOUR RESEARCH USES A LARGE AMOUNT OF COMPUTER MODELLING. IS IT ESSENTIAL TO BE GOOD AT COMPUTING TO STUDY GEOSCIENCES?

I use a lot of different computer programs for my work, many of which require writing code, but I actually have no formal training in computer programming. It would certainly be helpful to have some training in computer programming, but it's not 100% necessary.

OPPORTUNITIES IN GEOSCIENCE

- A degree in a science subject, such as geography or environmental science, is the most common route into geoscience
- Although some geoscientists have PhDs, it's not absolutely necessary to have a postgraduate degree to work in geoscience. Plenty of people with an undergraduate degree go on to work in industry or as a research assistant, for example
- The Glacier National Park, Montana, USA runs a glacier internship scheme: https://home.nps.gov/glac/getinvolved/pathways.htm
- The Glacier Society in Coral Springs are on the hunt for interns: http://glaciersociety.org/internship/
- Check out these opportunities for geoscience and geology internships worldwide: https://www.internships.com/geology
- A geophysicist in the US earns around $74,000 on average, but this can increase to $88,000 and above, depending on experience level and place of work. Geophysicists working in industry often earn more than those working in academia, for example

A small, 1km-wide glacier flows into the ocean in southeast Greenland.

ASK DR ELLYN ENDERLIN

HAVE YOU ALWAYS WANTED TO BE A RESEARCH SCIENTIST?

As a kid I briefly wanted to be a vet because I love animals so much, but I soon realised that this would be too emotionally challenging for me. I have always loved science and when I was about 12, I took part in a fun science fair project. It was then I started to think about getting a job focused on the environment.

WHAT EXACTLY INSPIRED YOU TO STUDY ENVIRONMENTAL AND GEOLOGICAL SCIENCES?

I grew up in a rural area at the base of the Appalachian Mountains and liked playing outdoors. My mom always encouraged me and my siblings to play outside and that led to a real passion for nature in all of us. I was interested in learning more about the environment and, once I got to college, I realised that I could make a career out of studying the environment. I knew that's what I wanted to do.

WHAT SPARKED YOUR INTEREST IN GLACIERS?

I knew very little about glaciers before I went to college, but I knew that I wanted to get a degree that would lead to a job studying the environment. I took a variety of science courses in my first year, including physics, chemistry, anthropology, geology and geographic information systems (GIS). I did really well in GIS, in particular, and that prompted my professor to invite me on a field trip to map glacier landforms in the Andes in Peru. It was an amazing experience. I had never even left the US before and I was struck by the glaciers' beauty, tremendous scale and profound sensitivity to climate change. I was hooked.

WHAT DO YOU LOVE MOST ABOUT YOUR JOB?

My favourite part of my job is that I get to decide what I'm going to research. If I have a good idea and I can convince my funders that it's worth exploring, that's what I get to do. It's almost like I'm my own boss. A close runner-up is that I have been able to travel to some of the most awesome places in the world. I've been to Greenland, Antarctica, Iceland, Svalbard, Peru, Alaska, and New Zealand for work and numerous places in Europe and the US for conferences.

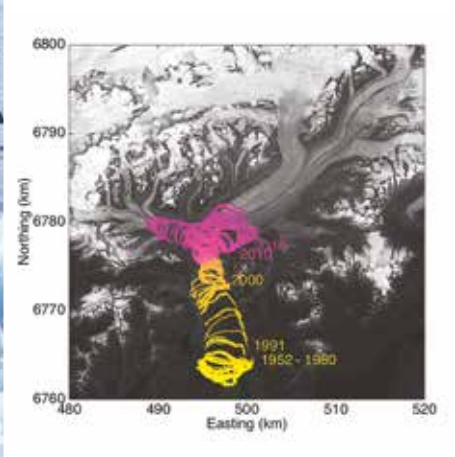
THERE AREN'T MANY ICEBERGS (OR GLACIERS) IN IDAHO! DO YOU SPEND A LOT OF TIME TRAVELLING TO GREENLAND?

Over the past couple of years, the majority of my work has been done using observations from satellites and aircraft, so I haven't done a lot of field work on glaciers recently. I do miss it, because glaciers are so incredibly beautiful, but it's also nice that I don't have to spend long periods of time away from my husband and son. However, I'm planning on matching more field and satellite observations in the near future. I think field data are absolutely necessary to understanding glaciers, and that everyone should get to see glaciers in person, especially if they are studying them!

ELLYN'S TOP TIP FOR STUDENTS

I recommend taking introductory physics and maths classes early on. A lot of students interested in geoscience are afraid that maths and physics are too hard for them. I actually didn't think I was very good at physics in high school and early in college, but once I started applying physics to the study of glaciers, I realised I just needed to be able to visualise it to understand its application better.

Landsat 8 satellite image of southeast Greenland from July 2014. This is a 'false colour' image. The colours aren't what you would see in the real world but in this image the ocean is black, the clouds over the ocean are the wispy white areas, the land is brown, and the ice is blue. Bright blue is snow on the Greenland Ice Sheet and darker blues are glacier ice.



A black and white Landat 8 satellite image of Columbia Glacier, Alaska, USA. Coloured lines mark changes in glacier length over time. A glacier's geometry strongly influences how it responds to environmental change. While Columbia Glacier's length decreased by ~25km since the 1980s, smaller changes in length have been observed at most other glaciers that flow into the oceans.

LEARNING TO LIVE WITH LESS WATER

CLIMATE CHANGE AND A GROWING POPULATION ARE PUTTING PRESSURE ON OUR GLOBAL WATER RESOURCES, ESPECIALLY THOSE USED FOR AGRICULTURE. HOW CAN WE RESPOND TO THIS CHALLENGE AND ENSURE THAT FARMERS HAVE THE WATER THEY NEED? **DR EMILE ELIAS** AND THE **USDA SOUTHWEST CLIMATE HUB** ARE WORKING HARD TO ANSWER THIS QUESTION.

IMAGINE THIS SCENARIO

Bella is 16 and lives on a farm. Sadly, there has been little rainfall in recent times, which means the region she lives in is in the grips of severe drought. Water sources are drying up, and without this water, farmers are unable to care for their crops. Production is at an all-time low, and it looks like Bella's parents may have to give up their farm, which has been in the family for many generations. Not only that, the farm is their livelihood, and Bella is worried about the future for her and her family.

According to the World Health Organisation (WHO), half of the world's population will be living in water-stressed areas by 2025. Many will simply not have the water needed to tend to their crops and livestock, among other things. Food production will be affected, and so will the livelihoods of thousands of people.

50%

of the world's population will be living in water-stressed areas by 2025

Climate change, and increases in the frequency, severity and duration of agricultural drought, have contributed to a shortage of water for agricultural use. In some parts of the world, poor land management practices and water wastage have put further strain on water supplies. Clearly, something needs to be done to ensure that our water resources are properly managed, especially in light of a rapidly changing climate and a growing global population.

Dr Emile Elias and her colleagues at the USDA Southwest Climate Hub hope that the knowledge gained through their research will ensure that our water resources are well managed and protected, and that, ultimately, farmers have enough water to support their livelihoods. Emile's area of focus is America's southwest – especially the upper Rio Grande basin in southern Colorado and northern New Mexico.

WHAT IS IT LIKE IN THE SOUTHWESTERN REGION OF THE US?

The southwest is one of the hottest and driest areas of the US. There is often very little rain. In fact, much of the area's water comes from snowmelt runoff from mountains during the spring. So, water can be in short supply.

Sometimes the area reaches a tipping point. "During the exceptional drought of 2018, for example, some communities ran completely out of water," says Emile. "Many had to haul water long distances and this negatively impacted agriculture in the region." Some farmers simply did not have the resources to support their livestock.

WHY IS THE WATER SCARCITY PROBLEM GETTING WORSE?

"Drought is a way of life in the region," says Emile. However, it appears that in recent times, things are different, with temperature-related agricultural droughts now intensifying.

Emile believes that the increasing frequency and severity of agricultural droughts are due, in part, to climate change, and Climate Hub's investigations into the amount of water held in snow in the San Juan and Sangre de Cristo mountains, and runoff (water produced from melting snow) into the Rio Grande river, are indicating that the situation is likely to get worse. "Warming temperatures are leading to lower amounts of water held in the snow, reduced soil moisture, and changes in runoff timing," she says.

WHAT HAVE HYDROLOGICAL MODELS SHOWN?

Emile and her colleagues used hydrologic simulation models in their studies (hydrology refers to the study of water and its distribution on Earth). A model is a simplified version of reality that allows for observation and testing. "In hydrologic modelling we use mathematics to represent reality. Simulation models are built from mathematical principles and generally use computing technology to test different scenarios," Emile explains.

To get a full picture of possible outcomes, the team modelled four potential climate scenarios over the next 80 years or so. The scenarios were as follows: 1) warm and wet;

2) warm and dry; 3) hot and wet; and 4) hot and dry. Considering all four scenarios, the researchers were able to summarise that total water volume of the basins in the area will be between 7% higher and 18% lower than pre-climate change conditions. Their models also showed that warming temperatures will lead to earlier peak snowmelt runoff. If the snow melts too soon, this poses challenges for water management in the region.

To add weight to the research team's findings, some of the changes they have predicted – such as a decrease in available water and snowmelt occurring earlier in the year – are already being observed in the region.

WHAT CAN BE DONE?

It's important for everyone to understand changes in climate in the region so they can plan for the future. They can then implement water management strategies, such as adapting crop irrigation practices; searching out alternate water sources; promoting better water use in cities; and collecting runoff via rain barrels for later use. They might even have to build suitable infrastructure to withstand flooding or soil erosion if the area experiences an increase in flooding and earlier snowmelt.

IS WATER SCARCITY A GLOBAL PROBLEM?

The short answer is, yes. And it is only set to continue. Half of the world's population will be living in water-stressed areas by 2025. In addition, the water shortages will only be exacerbated by climate change. And yet, this isn't the full story. Other areas of the world, including parts of the US, are experiencing too much rainfall and are having to manage the impact of floods. Too much water can be just as devastating for agriculture as droughts, which is why understanding shifting water availability and the work of Emile, her colleagues and the USDA Southwest Climate Hub are so vital.

DR EMILE ELIAS

Research Hydrologist and Acting Director
Southwest Climate Hub
US Department of Agriculture

FIELD OF RESEARCH

Hydrology and
Climate Change

RESEARCH PROJECT

Emile's research investigates how climate change, and the way communities use land, is affecting the quality and quantity of water in southwestern United States. She hopes that the insights gained will help residents to better manage their water supplies and secure a sustainable agricultural future.

FUNDER

United States Department of Agriculture (USDA)

Emile in front of the La Plata Mountains near Durango, Colorado

ABOUT THE USDA SOUTHWEST CLIMATE HUB

The USDA (United States Department of Agriculture) has ten climate hubs, or centres, which are devoted to managing Earth's resources in the context of a changing climate. One of these is the Southwest Climate Hub. We asked Emile about the vital work they do.

WHAT IS THE PURPOSE OF THE USDA SOUTHWEST CLIMATE HUB AND HOW DOES IT DIFFER FROM THE OTHER NINE REGIONAL CLIMATE HUBS?

All of the ten USDA Climate Hubs across the nation work to help farmers, ranchers, foresters and communities respond to the impacts of a changing climate. We conduct and synthesise research, provide educational workshops and materials and create decision-support tools and resources. The Southwest Hub covers a hot and dry region of the US, so we focus on water scarcity, drought, wildfire and adaptation related to warm environments with limited moisture.

THE SOUTHWEST CLIMATE HUB ALSO DOES A LOT OF OUTREACH AND EDUCATION WORK? WHY?

Our scientific translation needs to reach decision-makers to promote resilient agriculture and communities. So, we host workshops to provide people with important information. We also believe that providing climate-related education to youth will support future generations of scientific thinkers.

THE HUB HAS PARTNERED WITH THE ASOMBRO INSTITUTE FOR SCIENCE EDUCATION TO CREATE FUN AND SCIENTIFICALLY RIGOROUS EDUCATIONAL ACTIVITIES FOR 6-12 GRADE STUDENTS. THEY ARE AIMED AT TEACHERS, BUT CAN YOUNG PEOPLE USE THEM AT HOME OR BY THEMSELVES?

Absolutely! The activities are intentionally designed to use materials that could be easily and inexpensively acquired. Many people probably have the materials at home already. You'll find the activities here: https://asombro.org/climate-hub/

THERE ARE TWO CURRICULUM UNITS, WHICH ARE FREE TO DOWNLOAD: 'CLIMATE CHANGE AND THE WATER CYCLE' AND 'EFFECTS OF CLIMATE CHANGE ON AGRICULTURAL SYSTEMS'. WHY IS THE FOCUS ON WATER AND AGRICULTURE?

We selected water because water scarcity is critical to people and nature in our region. And projected changes to the hydrologic cycle are important for people to understand now to plan for the future. Agriculture was selected next because it is vital to our communities and economies; and agriculture can be vulnerable to changing conditions.

HOW POPULAR ARE THESE UNITS, AND WOULD THEY BE SUITABLE FOR STUDENTS IN DIFFERENT REGIONS OF THE US OR COUNTRIES WORLDWIDE?

Teachers who have used and tested these units are impressed. The units are growing in popularity because we are working to reach more teachers and to raise funds to offer supply kits to selected teachers across the Southwest. And yes, they would be suitable for students in different regions of the US or other countries. Even though the activities focus on climate change issues in the southwest of the US, many of the issues are common in other areas of the world.

DOES THE SOUTHWEST CLIMATE HUB OFFER TRAINING OR APPRENTICESHIP SCHEMES FOR YOUNG PEOPLE?

The Climate Hub network has a highly competitive fellowship programme for early career scientists. We also have a cohort of undergraduate students at the Southwest Climate Hub who learn about climate science, outreach and tool development. We host webinars with a variety of partners which are recorded and shared via www.drought.gov.

> *"We believe that providing climate-related education to youth will support future generations of scientific thinkers."*

Members of the Southwest Climate Hub Steering Committee

ASK DR EMILE ELIAS

WHAT DID YOU WANT TO BE WHEN YOU WERE YOUNGER?

By late elementary school, I knew I wanted to work with water. After getting an undergraduate degree in biology, I was headed to law school to study water law, but quickly realised that my true passion is science.

HOW DID YOU BECOME INVOLVED IN HYDROLOGY?

My family took an annual trip to the Colorado mountains and I became fascinated by the rivers and lakes in Colorado. My first science field trip was in third grade to a local pond. And then I volunteered with a local non-profit group to sample water quality in high school. I took any opportunity I could to learn about water.

WHAT DO YOU LOVE MOST ABOUT YOUR JOB?

I love working with a highly engaged team of scientists to foster climate-informed decision-making. The "science to practical application" aspect of my job, and our motivated and thoughtful team, make my work truly enjoyable.

WHAT OPPORTUNITIES ARE THERE FOR YOUNG PEOPLE IN HYDROLOGY?

You could start in the field sampling water conditions, and studying macroinvertebrates and other indicators of aquatic health. Or, you could use technology, such as hydrologic modelling, to try to predict the impacts of changes to water resources. Or, you could engage in policy or law to influence water resource management. There are also opportunities in the non-profit, academic, governmental and legal fields.

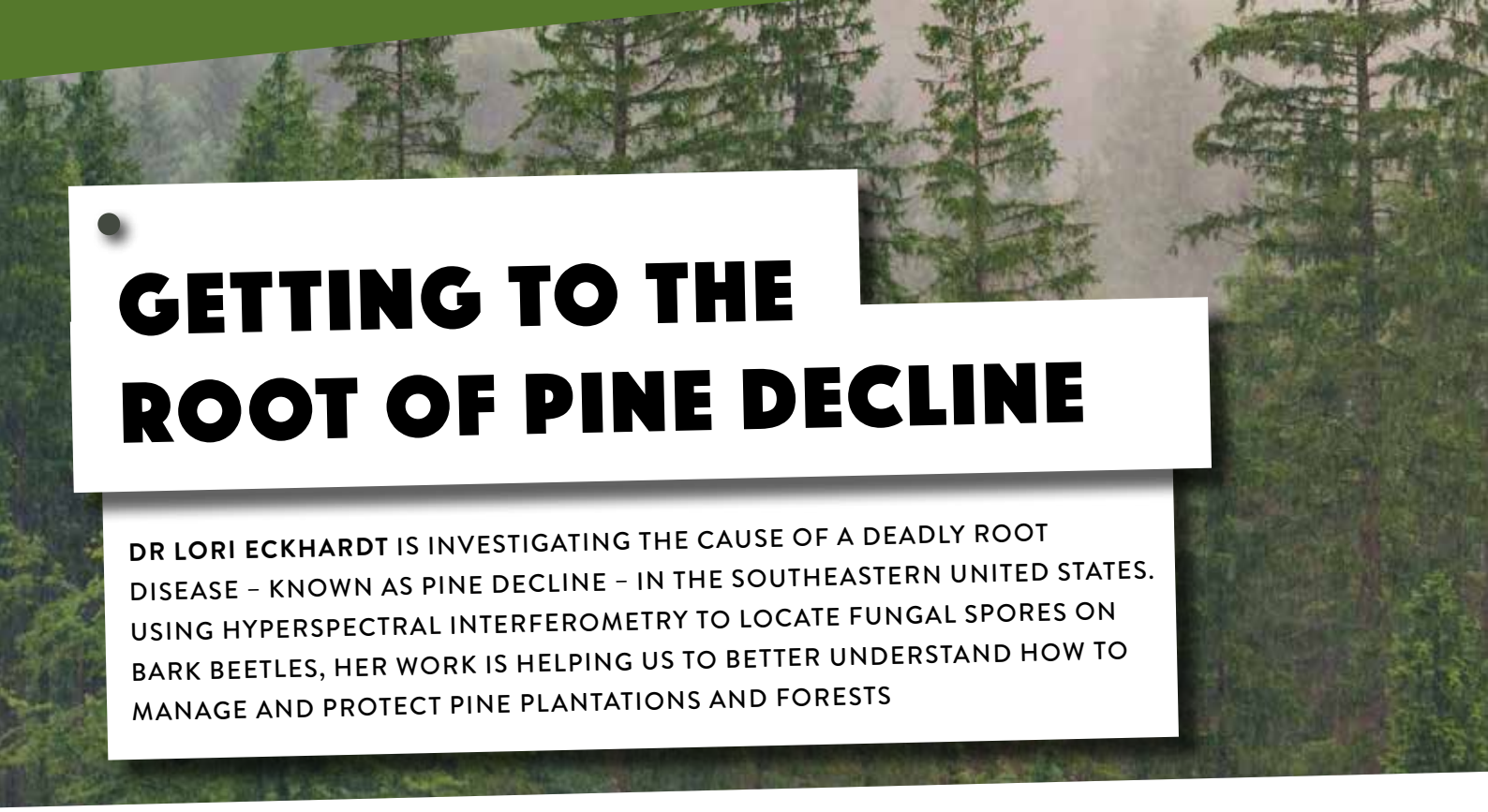
IF YOU COULD GO BACK IN TIME WHAT ADVICE WOULD YOU GIVE YOURSELF WHEN YOU WERE STARTING OUT ON YOUR CAREER PATH?

I'd say, "Be flexible and open to your path unfolding in unexpected ways, and choose to learn and do what you love."

OPPORTUNITIES IN HYDROLOGY

- Firstly, to see if hydrology and related climate research is for you, you could participate in local community-based initiatives and climate action groups, perhaps even those organised by your school.
- Most people working in the hydrologic field go to university, but not all necessarily get a Master's degree or PhD. There are many opportunities for people with an undergraduate degree in aquatic ecology, hydrology and water resources management.
- The pay for a hydrologist in the US varies by sector and experience. A starting hydrologist earns about $50K per year, whereas an experienced hydrologist can earn around $120K per year, and sometimes more.

Emile and her family raft the Animas River, Colorado



GETTING TO THE ROOT OF PINE DECLINE

DR LORI ECKHARDT IS INVESTIGATING THE CAUSE OF A DEADLY ROOT DISEASE – KNOWN AS PINE DECLINE – IN THE SOUTHEASTERN UNITED STATES. USING HYPERSPECTRAL INTERFEROMETRY TO LOCATE FUNGAL SPORES ON BARK BEETLES, HER WORK IS HELPING US TO BETTER UNDERSTAND HOW TO MANAGE AND PROTECT PINE PLANTATIONS AND FORESTS

WHAT IS HYPERSPECTRAL INTERFEROMETRY?

When we look at a rainbow, the colours we see are just a section of the electromagnetic radiation spectrum. There is, in fact, a lot more to this spectrum: infrared, ultraviolet light, X-rays, microwaves (not ovens!) and radiowaves. Hyperspectral imaging allows scientists to look at objects using the vast proportion of the electromagnetic spectrum, beyond what we would normally see with the human eye.

Objects (including insects and fungi) leave unique 'fingerprints' in the electromagnetic spectrum known as spectral signatures. And it is these signatures that allow scientists to identify the object. For example, geologists use a spectral signature for oil to find new oil fields.

Lori has been using this tool to look for ophiostomatoid (ō'fi'os-tō-mä'toi'd) fungi spores on bark beetles, which has exciting prospects for discovering other insects that carry harmful fungi.

Whether it's furniture, flooring, toilet roll or paper, many items in our homes are made from pine. Pine trees are native to the Northern Hemisphere and are among the most important trees for timber and other industrial and household products. One region that is heavily reliant on pine is southeastern US. Here, pine trees are grown in plantations, bringing in billions of dollars to the local and national economy, and creating millions of jobs. But, a deadly root disease is taking hold, endangering pine trees that are already under a lot of stress, as well as the industries that rely on this vital wood crop.

Based at Auburn University in Alabama, USA, Dr Lori Eckhardt is an entomologist and forest pathologist. This means she studies insects (entomology) and diseases affecting a forest ecosystem (forest pathology). She is looking into the reasons behind pine decline, which has become a major issue for southeastern US in the last 20 years. Focusing particularly on the bark beetle and ophiostomatoid (ō'fi'os-tō-mä'toi'd) fungi, Lori's aim is to find new ways to manage and prevent this root disease.

WHAT IS PINE DECLINE?

Pine decline is a complex disease. This means that the infection is a result of many interacting factors such as insects, fungi, soil type and climate. Trees suffering from pine decline show signs of bark beetles and ophiostomatoid fungi in their deteriorating roots.

IS PINE DECLINE CAUSING TREES TO DIE IN LARGE NUMBERS IN SOUTHEASTERN US?

It's not known whether pine decline is the main factor responsible for the death of pine trees because there are so many stressors involved, including pollution, changes in weather patterns and temperature, urbanisation, insect pests, fungal pests and others.

One stressor, for example, is the introduction of non-native pests. Insects like gypsy moth or emerald borer weren't originally from the US, but they were unintentionally transported to the country through human travel and international trade. These insects have managed to adapt to their new environment and cause devastation to trees and plants that haven't had the time to evolve and develop full resistance to them. "Non-native insects can wipe out entire species of trees and plants, altering ecosystems and affecting wildlife," says Lori.

WHAT DO WE KNOW ABOUT BARK BEETLES?

Although often described as 'pests', root-feeding bark beetles can provide great benefits such as nutrient cycling to forests. Similar to a water cycle, the nutrient cycle is the movement of nutrients such as calcium, potassium and magnesium within an ecosystem. The problem is, root-feeding bark beetles can become aggressive in large numbers and, as their name suggests, will attack the bark, roots and lower trunk of trees.

Due to acid rain, industrialisation, toxic gases from vehicles and all the factors mentioned above, pine trees are under a great deal of stress, and are therefore more susceptible to bark beetle invasion. Not only that, but the beetles' symbiotic relationship with ophiostomatoid fungi or 'blue stain fungi' can wreak havoc on stressed pine trees. The fungi are known as blue stain fungi because they leave blue stains in the wood, making it less viable for the wood industry.

DR LORI ECKHARDT

Professor and Director
Integrated Forest Pathology
and Entomology
Forest Health Cooperative, School
of Forestry and Wildlife Sciences,
Auburn University, USA

FIELD OF RESEARCH

Forest Pathology and Entomology

RESEARCH PROJECT

Lori's work aims to shed light on the way diseases spread in forests. Part of her research involves investigating the relationship between bark beetles and blue stain fungi, and their impact on pine trees in the southeastern US.

FUNDERS

The Forest Health Cooperative, McIntire Stennis, National Science Foundation, Unites States Department of Agriculture, United States Forest Service and the School of Forestry and Wildlife Sciences

WHAT IS THE BEETLE'S RELATIONSHIP WITH OPHIOSTOMATOID FUNGI?

Bark beetles pick up fungal spores while building homes and hunting for food. The spores attach to the beetle's body, penetrate its exoskeleton (outer covering) and then grow inside them. This may not sound great, but because their relationship is symbiotic – when two organisms have evolved to live closely together – there are usually benefits. Not only does the fungi offer bark beetles another source of food, they also appear to alter the nutrient content of tree tissue, making it tastier for the beetles!

SO, WHY IS THIS SYMBIOTIC RELATIONSHIP WREAKING HAVOC?

The fungi are essentially getting a "free ride", says Lori. "When beetles tunnel into tree tissues, the fungi gain a foothold as well, lowering moisture content of the tree and dividing up the tree's defensive resources as it fights against two invaders instead of one." The fungi stop the trees from being able to pull up water from their roots to their leaves by obstructing the xylem (zi'ləm), vessels that carry water and minerals.

WHAT DOES LORI'S RESEARCH SHOW?

There are over 100 different types of pine and quite a few types of ophiostomatoid fungi, too. Lori's research – and the work of other forestry pathologists and entomologists like her – is incredibly important in understanding how species interact with each other in an ecosystem, and which plants and insects are more vulnerable to threat. For example, Lori has found that, in high doses, one type of ophiostomatoid fungi, *Leptographium terebrantis*, can cause trees to die outright. Other species of ophiostomatoid fungi, particularly those that are native to the southeastern US, aren't as destructive.

Lori has been using innovative microscopic imaging technology (hyperspectral interferometry) to look for fungal spores on the bodies of bark beetles. What's exciting is that this method has the potential to enable scientists to identify the species of fungi, particularly in areas where a significant number of trees are experiencing pine decline. If the people in charge of managing pine forests and plantations have this information, they can make quick and cost-effective decisions on how to deal with these insect and fungal pests.

Leptographium terebrantis

Leptographium procerum

ABOUT FORESTRY AND FOREST PATHOLOGY

"Young people should be interested in forestry!" says Lori, who started working in forest research before getting into entomology. "Wood products provide many of our everyday materials, from houses to deodorant, clothing and electronics – and even medicine. Unlike the waning hype of some industries, forestry will always be needed to maintain a thriving society."

There are so many aspects to forestry (see Opportunities in forestry) and forest pathology, but one example that relates specifically to Lori's work is understanding what makes trees vulnerable to attack from pests and disease. Imagine knowing which species of pine is hardier than others (longleaf pine has a natural defence against bark beetle attack), or learning how to control or prevent the spread of diseases that affect trees, forests and wildlife.

"Learning how to control the spread or prevent the establishment of certain fungi can save millions of dollars, increase revenue and save lives," says Lori. "Diseases that cause debilitation and death can be prevented or treated early. Likewise, food production can be increased and kept stable if knowledge of pest fungi can keep food stores from becoming contaminated and destroyed. Food animals can be influenced by fungi that invade feed and release toxic chemicals. Even humans can become sick through the inhalation of spores."

Like Lori, you, too, could advise policymakers and landowners on how to manage and protect one of our most vital resources: forests.

OPPORTUNITIES IN FORESTRY

- Study forestry and you could become a forest biologist, professional forester, wood engineer, forestry business administrator, conservationist, renewable resource manager, and much more.
- As an applied science, a forestry education can also open doors to professions in education, business and law.
- Check out Forestry Works for info on careers that are open to you in forestry.

ABOUT ENTOMOLOGY

Entomology is the study of insects and their relationship to humans, the environment and other organisms. Lori didn't set out to become an entomologist but, as she explains, this field is extremely important: "Insects provide the basis for life on earth, influencing plant and animal populations by pollinating crops, spreading seeds, acting as biocontrol of weeds, providing food to wildlife and spreading disease".

"In addition to this, insects aid in decomposition and nutrient recycling, allowing for nutrients to be available to plants and spreading fungi that aid in this," she continues. "Many insects, such as butterflies, are inherently beautiful and add to the beauty of life on Earth. Preservation of these are attractive to people wishing to see them for generations to come, and their bodies can provide attractive ornaments for jewellery and clothing."

"Lastly, insects play a negative role in our food production and medical field as well, devouring crops or invading stores, such as wheat or flour, and spreading diseases that cause mortality. Control of these pests is necessary to feed populations, maintain the food industry and save lives."

Imagine having the knowledge to protect vital pollinating insects like bees – or control pests that destroy food crops. Like Lori, you, too, could use new technologies to study and learn about the roles of insects on our planet.

OPPORTUNITIES IN ENTOMOLOGY

- According to About Bioscience, around 8,000 people work as professional entomologists in the US, earning between $25,000 to $75,000 per year on average.
- Entomologists may work in research, education or for government agencies.
- Forensic entomology is a new field of study. Entomologists working in this field use their knowledge of insect life cycles and behaviour to help the police solve crimes.
- Agricultural entomology is incredibly important, considering that insect pests can cause up to a 25% loss in crop yields. Check out the youth organisation Future Farmers of America for resources and information on agricultural education.

ASK DR LORI ECKHARDT

YOU HAVE AN ASSOCIATE IN ARTS DEGREE IN MERCHANDISE MARKETING FROM THE FASHION INSTITUTE OF DESIGN AND MERCHANDISING. HOW DID YOU COME TO WORK IN FORESTRY AND ENTOMOLOGY?

I previously worked in retail when I left high school and was also in the Navy Reserves, which is where I met my husband. The Navy moved us around a lot, and so I took the opportunity to go back to school. As we were stationed in Maryland, I decided to enrol at the University of Maryland to study cell molecular biology and genetics.

I managed to get a job in a lab and obtained a research fellowship working on tobacco mosaic virus. It was at that moment I fell in love with research.

I was contacted by my former advisor about a project that involved working with beetles and blue stain fungi. At the time, I knew nothing about fungi and didn't really like insects, but the project sounded very interesting, so I decided to take it on. I visited Louisiana State University and my career in forest pathology and entomology began from then onwards.

WHAT DO YOU LOVE MOST ABOUT YOUR JOB?

I love that it involves both working indoors and outdoors. While I love being in the lab, it's amazing to be out and about in nature, as well as seeing how everything works together in an ecosystem.

IF YOU COULD GO BACK IN TIME, WHAT ADVICE WOULD YOU GIVE YOURSELF WHEN YOU WERE STARTING OUT ON YOUR CAREER PATH?

I often think I would tell myself to start this career much earlier and not work in fashion or the military, but I know I did the right thing.

I have travelled all over the world, learned so much about various cultures and have worked with many different people. Those experiences are invaluable, and they've helped shape me into the person I am today.

You don't always need to know exactly what you want to do at first. I'm proof that you can succeed in more than one career in your lifetime!

LORI'S TOP TIPS

1. Be curious! Get out and see nature!

2. Read books and learn what you can about forestry, entomology and plant pathology.

3. Start an insect/mushroom collection and see how many different varieties you can find.

4. Ask questions.

5. Find out what kind of plants live in your area and discover a cool fact about these plants.

6. Meet and talk to different people to find out how and where to follow your passions.

Opie the "Timber Dog" sniffing out pathogenic root fungus

SAVING PLANTS FROM DISEASE

TO PREVENT OUTBREAKS OF DISEASE DESTROYING WHEAT AND OTHER VITAL FOOD CROPS, SCIENTISTS FROM THE **ROTHAMSTED RESEARCH** AND **EUROPEAN BIOINFORMATICS INSTITUTES** ARE SHARING GENETIC AND GENOMIC INFORMATION ON DISEASE-CAUSING MICROORGANISMS

WHAT'S THE PROBLEM?

Every year, up to one-quarter of plants grown for food are spoiled or killed outright by disease before the crop can be harvested. Those that survive are sometimes later destroyed by disease while being transported around the world. It's hard to predict where in the world new outbreaks will happen. As the world warms up due to climate change, the micro-organisms (fungi, protists, bacteria and viruses) that cause diseases are gradually moving towards Earth's poles. They can also be carried to new locations by severe storms, and inadvertently by humans, animals, or traded goods. So, what can be done to solve this problem?

UP TO 1/4

OF PLANTS GROWN FOR FOOD ARE SPOILED OR KILLED OUTRIGHT BY DISEASE

To prevent plant diseases, scientists at the Rothamsted Research and European Bioinformatics Institutes are sharing detailed genetic and genomic information about "pathogenic organisms" contained in two databases: PHI-base and PhytoPath.

WHAT ARE THE PATHOGEN-HOST INTERACTIONS DATABASE (PHI-BASE) AND PHYTOPATH?

PHI-base and PhytoPath are databases that help researchers discover more about organisms that cause disease (plant pathogens). Scientists use these databases to look up information on a pathogen to find out which genes and gene clusters are responsible for infecting a plant (the host). This improved knowledge is important for devising ways to prevent diseases from occurring in the first place, or to reduce the spread of disease because a disease may go on to infect either more plants of the same species, or other plant species.

Genes provide the instructions that tell plants, animals and humans how to make proteins, including enzymes and chemical messengers. In humans, for example, a variety of genes determine the colour of your eyes or hair, and we inherit different genes from each of our parents depending on the genetic segregation battles that take place in specific cells. All of the genes in a given organism make up its genome (its DNA blueprint), and it's the DNA sequence of genes that govern the proteins, enzymes and chemical messengers that are produced. The genes known to cause pathogenic diseases are included in PHI-base. These can be accessed from PhytoPath, as well as whole genome sequences that it pulls in from another database called Ensembl.

PHI-base is updated regularly, with the latest version including data on 6,438 genes from 263 pathogens and 194 hosts. It provides detailed information on the genes that affect the outcome of interactions between pathogens and hosts. It also gives information on 'host target sites', which detect the presence of a pathogen and activate the plant's defences.

WHAT KIND OF ORGANISMS CAUSE PLANT DISEASES?

PHI-base and PhytoPath include data on three types of plant pathogen: fungi, bacteria, and single-celled organisms called protists. For example, a fungus that causes stem rust is called *Puccinia graminis*; a bacterium that stops rice seeds from growing is called *Burkholderia glumae*; and a protist that causes potato blight is called *Phytophthora infestans*.

Too small to be seen with the naked eye, protists are sometimes called water moulds. That's because many species can swim in water, thanks to a microscopic whip-like appendage called a flagellum. Many protists are dispersed and infect plants only when it rains. As well as infecting plants, protists are also responsible for major diseases in humans and animals, including malaria.

Strange as it may seem, not all diseases caused by pathogens are undesirable. The *Botrytis cinerea* fungus causes grey mould disease on a large number of fruit and vegetable species, which is definitely unwanted. But it is also responsible for 'noble rot', which wine producers love. Grapes that pick up this infection at the right time produce fine, concentrated sweet wine.

WHO USES THESE DATABASES?

Biologists, molecular geneticists and molecular biologists use PHI-base. They can find out how a variation in a gene, called a mutation, affects its characteristics. For example, a mutation might make the pathogen more or less virulent (harmful). Or scientists may have an interest in a specific phenotype (appearance or trait) that they wish to find out more about.

Other scientists, known as bioinformaticians and computational biologists, use PHI-base and PhytoPath to study organisms using computers. They compare different species, identifying the genes or sets of genes linked to a particular pathogen or host. Before PHI-base and PhytoPath, it would have taken months for scientists to get hold of this combined genetic and phenotypic data.

HOW WILL PHI-BASE AND PHYTOPATH HAVE THE BIGGEST IMPACT?

Plant pathogens are a major problem for agriculture around the world. In the case of a new disease outbreak, these two databases will provide valuable information so that governments and industries can act quickly to stop diseases spreading. Once a disease-causing organism has been analysed, information on its genes and genome will be available within a few days to weeks of any outbreak.

One way of stopping diseases killing or disabling plants is to spray them with pesticides. Thanks to detailed genetic and genomic data, manufacturers of anti-infectives will be able to make them more effective. Prevention is an even better way of stopping diseases. Plant breeders can exploit the data in PHI-base to create new, more resilient crops. They'll be able to learn more about how the genes and proteins of a host can detect a pathogen's presence and activate its defences.

CAN STUDYING PLANT DISEASES IMPROVE HUMAN HEALTH?

Yes. *Alternaria alternata* causes a disease in plants called leaf spot and has been known to cause upper respiratory tract infections and asthma in humans. It's just one of many microscopic fungi with the ability to infect plants as well as animals and humans. We know far less about these "hidden killers from the fungal world" because we have studied them far less than diseases caused by bacteria or transmitted by insect vectors. Sometimes, such diseases can escalate, infecting several members of the same family or even spreading to different countries. Because the diseases caused by these pathogens spread in similar ways in plants and humans, we can learn a lot by comparing different species.

WHO ELSE IS INVOLVED IN THE PROJECT?

The scientists working on PHI-base and Phytopath are based at the Rothamsted Research Institute in Hertfordshire, UK, and the European Bioinformatics Institute in Cambridge, which is part of EMBL, Europe's flagship laboratory for the life sciences. They collaborate with scientists working at the University of Cambridge and also with data specialists at Molecular Connections in Bangalore, India. The University of Cambridge scientists are part of a global research community called PomBase working on the model fungal fission yeast species. The PomBase team is helping to develop a new tool – PHI-Canto – to allow scientists to enter new information in PHI-base. Molecular Connections, meanwhile, reads and extracts the required information from specialist life science publications (using a method called information curation / biocuration) and also updates the interface to make PHI-base easier to search.

WHAT ARE THE CHALLENGES INVOLVED IN THIS KIND OF RESEARCH?

The amount of data that is being generated across the life sciences has grown enormously in recent years. One estimate is that the amount of genomic data will double every seven months! In 2020, data will be generated a million times faster than it was less than 10 years earlier. The task of storing and transmitting all this data is too big for one country alone to handle. That's why a European organisation has launched a "big data" project called "ELIXIR-Data for life" to collate all this information and make it available so that scientists across Europe can use it to make discoveries.

ELIXIR will link all the databases together so that you can use one interface to look up genetic and genomic information anywhere – much like a web browser can find information held on different computers. PHI-base supplies agrigenomics data (agriculture-related genetic information) to ELIXIR. In total, 23 countries are members of ELIXIR and, in the UK, 15 universities and research organisations are involved in the project.

WHAT DOES THE FUTURE HOLD?

Over 70% of the genes predicted in the genome of every pathogenic species have no known function. There is a lot that remains to be discovered before we fully understand how pathogens cause disease and how host species stop infections.

FIVE DEADLY PLANT PATHOGENS

PHYTOPHTHORA INFESTANS: This protist caused the world's most deadly potato disease. Between 1845 and 1851, it was responsible for the Irish Potato Famine, which led to the deaths of 21% of the Irish population. This is still the number one potato disease, globally.

MAGNAPORTHE ORYZAE: This fungus causes rice blast disease – the world's number one disease affecting rice. In some parts of the world, its close cousin now infects wheat.

PUCCINIA FUNGAL RUST FAMILY: The individual species in this family specialise in causing diseases in specific cereals. For example, black stem rust disease on wheat is a major problem for agriculture, which, in the 1950s, completely destroyed the USA wheat crop for several years.

FUSARIA FUNGAL FAMILY: The species in this family affect cereal crops as well as bananas, tomatoes and vegetables. They can also cause illness in humans, including eye disease and, in some people, diseases of the lungs and blood. These fungi are also able to live in the soil and on decaying plant tissue once a crop is harvested.

COLLETOTRICHUM KAHAWAE: This fungus causes coffee berry disease. In 1869, it devastated so many coffee plantations in Ceylon (now Sri Lanka) that farmers switched to growing tea. Tea leaves were exported to Britain, creating a nation of tea lovers in the process!

ASK DR KIM HAMMOND-KOSACK AND DR PAUL KERSEY

HOW DID PHI-BASE AND PHYTOPATH BEGIN?

Kim: I wanted to discover how pathogens attack plants to cause disease. Between 1999 and 2002, with the help of Dr Martin Urban, I curated all the relevant published papers into an Excel table. We realised there wasn't a database available for the type of gene function we were interested in, so in 2003, the Excel sheet turned into the database called PHI-base.

Paul: PhytoPath came about because I was looking to connect Ensembl (a database I was already operating) to more functional data from pathogen species – and PHI-base was an obvious partner.

WHAT WAS THE KEY DISCOVERY IN YOUR FIELD OF RESEARCH?

In the early 1980s in California (USA), Doug Dahlbeck, Noel Keen and Brian Staskawicz carried out a game-changing experiment concerning bacterial avirulence genes, which trigger disease resistance during infection of a specific host plant. They used a method called "shotgun cloning" of the entire genome from one avirulent race of bacteria and transferred this in small fragments into a virulent race. When the correct DNA fragment was chosen, this changed the virulent race to avirulent – one that didn't cause disease. By 1999, around 100 bacterial avirulence genes had been cloned and this data was curated into PHI-base.

WHAT'S NEXT FOR PHI-BASE AND PHYTOPATH?

We've developed a tool, PHI-Canto, to enable scientists to enter new information directly into PHI-base. Now, we need to make videos and publicise it! We also want to catalogue the pathogen target sites of all known anti-infective chemistries for fungicides, bactericides and antibiotics, alongside the variant mutant genes that lead to unwanted microbial resistance to these chemistries.

WHO'S WHO IN THE RESEARCH TEAM

KIM HAMMOND-KOSACK

Co-founder and team leader of PHI-base

Key skills: plant pathology, molecular plant pathology, genetics and molecular genetics, bioinformatic analysis of pathogen genomes.

Nationality: British

Why I love my job: I want to improve the health of crops, humans, animals and natural ecosystems.

Fun fact: I love photographing the natural world!

Kim has more than 30 years' experience in molecular plant pathology and genetics, investigating the harmful fungi and viruses that infect various food plants such as wheat, tomatoes and oilseed rape. Kim and her research team work at the cutting edge with these infectious organisms – combing through their newly decoded genomes (DNA blueprints), looking for any weakness in their defences. They then share this information online with scientists who are fighting to protect their own food supplies all over the world.

Funder: Biotechnology and Biological Sciences Research Council (BBSRC)

PAUL KERSEY

Investigator
Key skills: Bioinformatics
Nationality: British
Why I love my job: I'm interested in understanding the science, but it helps that the cause is so obviously important to mankind.
Fun fact: I was once deported from Russia!

MARTIN URBAN

Co-founder of PHI-base
Key skills: Molecular plant pathology of fungal pathogens, computer sciences
Nationality: German
Why I love my job: I'm fascinated by, and really enjoy, understanding how microbial pathogens can infect plants and animals.
Fun fact: I love jazz!

NISHADI DE SILVA

Project leader
Key skills: Bioinformatics, computer science, science communication
Nationality: British Sri Lankan
Why I love my job: The work I'm involved in is directly linked to improving health and welfare.
Fun fact: I love running!

ALAYNE CUZICK

PHI-base biocurator
Key skills: Biocuration (organising biological data and making it accessible)
Nationality: British
Why I love my job: I have always been fascinated by nature – it's so essential for the health of the planet.
Fun fact: I love plants – I always have at least 10 at home!

HELDER PEDRO

Bioinformatician
Key skills: Genomics, computer programming, web development
Nationality: Portuguese
Why I love my job: PhytoPath helps to research crop protection in an environmentally-friendly way.
Fun fact: I'm very sarcastic!

JAMES SEAGER

Software developer
Key skills: Software development and training
Nationality: British
Why I love my job: I believe in the value of sharing knowledge and using technology to simplify complicated tasks.
Fun fact: I can rapidly shake my eyeballs!

ABOUT BIG DATA, MOLECULAR BIOLOGY AND MOLECULAR GENETICS

WORKING TOGETHER, THE RESEARCH TEAM HAS SKILLS IN ALL OF THE FOLLOWING FIELDS!

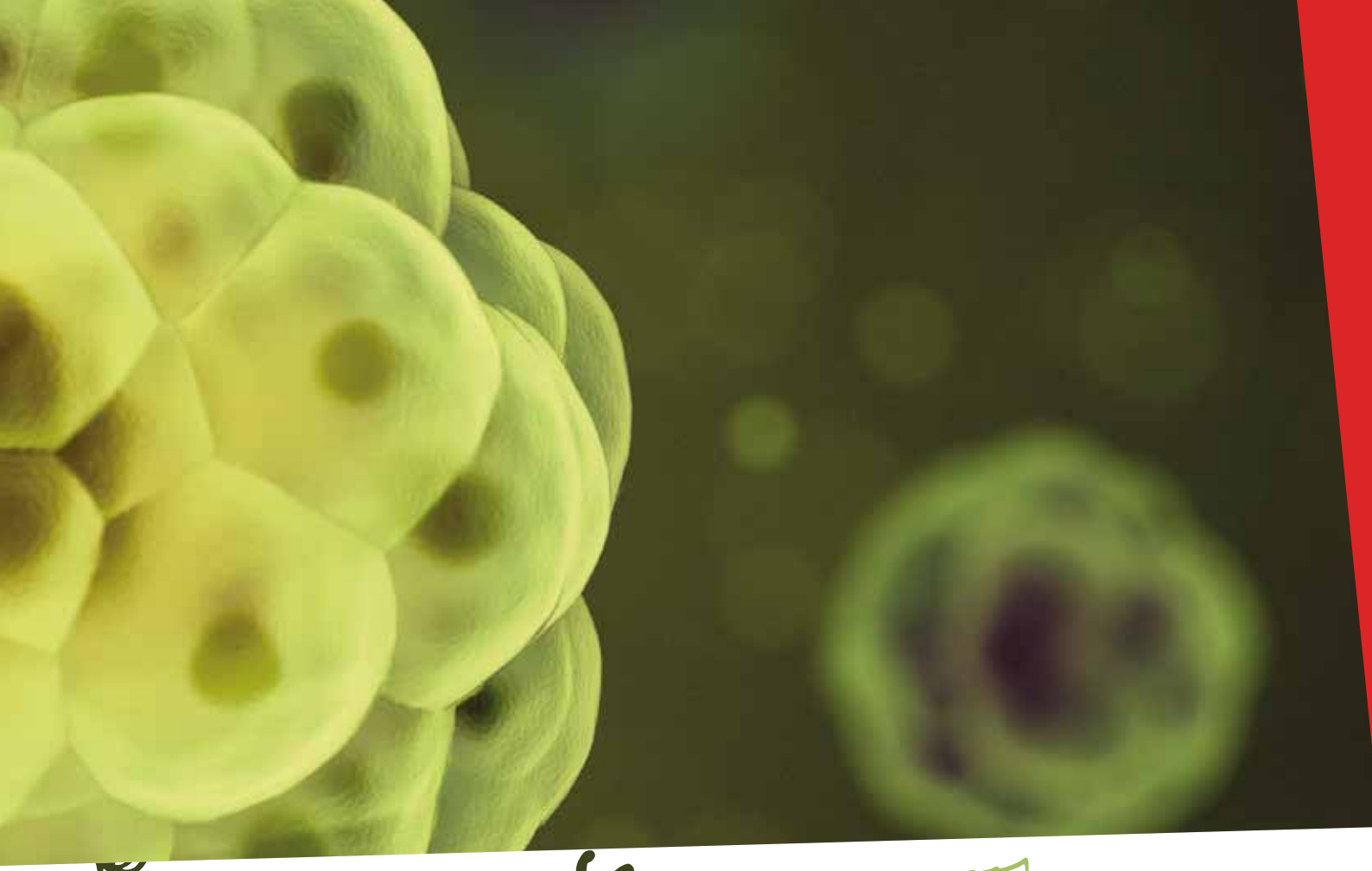
- Big Data
- Molecular Biology
- Molecular Genetics
- Informatics (Handling, analysing and displaying complex and large datasets)
- Bioinformatics, especially Comparative Genomics (where genome sequences of different species are compared)
- Molecular Plant Pathology
- Plant Disease Resistance/Plant Defence
- Host and Pathogen Target Site Discovery
- Effectoromics (the study of small entities produced by pathogens that are directly transferred into the host to make it unwell).
- Ontologies (English language for literature curation and the development of controlled vocabularies)
- Database Engineering/Computer Programming

WHAT ARE BIG DATA, MOLECULAR BIOLOGY AND MOLECULAR GENETICS?

BIG DATA: Modern biological experiments generate huge quantities of data. If we can organise and describe these data properly, we can look for statistically significant patterns, which can suggest mechanisms of action. Computers can even learn to draw these conclusions for themselves – this is one type of what is often called "artificial intelligence". To give you an idea of the scale of the databases Kim's team is working with, Ensembl has around 65 terabytes of data: this is equivalent to the combined storage of 254 entry-level Apple MacBooks!

MOLECULAR BIOLOGY: At the heart of living systems is the interaction of chemical compounds known as molecules. The term "molecular biology" usually refers to the study of molecules involved in heritable traits, such as DNA. But its discoveries have also produced a powerful toolset for all types of biological investigation. For example, by artificially altering the DNA of a cell, we can experimentally test what happens to an organism when a gene is absent or altered.

MOLECULAR GENETICS: Molecular genetics is a sub-discipline of molecular biology, particularly focused on functional units of DNA (known as genes) and exploring the different ways genes are inherited in families and across populations.



WHO USES DATABASES LIKE PHI-BASE AND PHYTOPATH?

- Evolutionary biologists studying how plant and pathogen genomes change and adapt over space and time
- Chemists using the newly found host and pathogen target site for the discovery of new drugs
- Plant breeders using effectoromics to select the most resistant/least susceptible plants to take forward in their breeding programmes
- Molecular biologists devising speedy pathogen diagnostic tests
- Computer modellers simulating pathogen movement locally, regionally and globally, and predicting disease epidemics and larger scale pandemics in advance
- Government scientists preparing legislation to cover particularly problematic pathogens and devise suitable quarantine measures at borders
- Governments and Non-Governmental Organisations helping farmers decide what crop species to grow/not to grow because of the anticipated changes in pathogen pressures

OPPORTUNITIES IN BIG DATA, MOLECULAR BIOLOGY AND MOLECULAR GENETICS

- The range of job opportunities in these sectors is predicted to grow dramatically in the future, and one way to make yourself highly employable is to take A levels (or equivalent qualifications) in biology, maths *and* computer science.
- Each year, the Nuffield Foundation offers 1,000 students – who are based in the UK and in post-16 education – paid placements to work alongside scientists, engineers, technologists and mathematicians. You have to be studying a STEM subject to qualify. Why not apply to work alongside researchers such as Kim and Paul, and find out what it's like to be a molecular biologist? http://www.nuffieldfoundation.org/nuffield-research-placements
- According to My World of Work, biologists and biochemists earn on average £43,680 per year in the UK. One big plus with a career in science is that, from your early 20s, you're paid to travel, interact with other scientists, and present your new research findings at national and international conferences and workshops.

NIALL ROGERS

BSc (Hons) Computer Systems Integration

University of the West of England (UWE), UK

CURRICULUM VITAE

7 GCSEs Grade C and above
(Maths retake C; Double Science C C)

BTEC Level 2
Information Technology (IT)

BTEC Level 3 IT Extended Diploma

WHAT IS COMPUTER SYSTEMS INTEGRATION?

There are many different types of computer systems. PCs, games consoles and smartphones are just some examples of a computer system, and all of them rely on different software applications to work properly.

System integration involves linking these different computing systems and software applications together so that they work as one computer system. For example, smartphones, PCs and games consoles need access to the internet and WiFi.

Take a look at BBC Bitesize Introducing Computers for more info.

"THE GOOD THING ABOUT A CAREER IN COMPUTING IS THAT YOU CAN LIVE IN YOUR DREAM LOCATION - EVEN IF IT'S YOUR HOMETOWN - AND STILL WORK FOR ANYONE IN THE WORLD."

SMART STUDENTS MAKE SMART THINGS

Students in their final year at UWE use the knowledge they have learned to make smart technologies. Here are two examples:

1) An alarm clock that automatically changes the time it wakes people up if the traffic is bad.

2) A device that uses Xbox Kinect to help people who are visually impaired to navigate around a room.

ENGINE CONTROL

SPEED	235	K
ACCELERATION	54	%
PRESSURE	63	MPH
FUEL LEVEL	175	MSV/H

"HE SAID I COULD BE THE NEXT Q IN JAMES BOND"

NIALL DIDN'T THINK HE WAS PARTICULARLY GOOD AT ICT, AND HE WASN'T KEEN ON GOING TO UNIVERSITY. NOW IN HIS SECOND YEAR AT THE UNIVERSITY OF THE WEST OF ENGLAND, WE ASK HIM HOW HE ENDED UP STUDYING COMPUTER SYSTEMS INTEGRATION

SCHOOL YEARS

WHEN YOU WERE IN YEAR 9 AT SCHOOL, YOU DECIDED TO TAKE THE BTEC IN INFORMATION TECHNOLOGY. WHY DIDN'T YOU TAKE THE GCSE IN COMPUTER SCIENCE?

At the Year 9 parents' evening, my IT teacher told me I should do IT GCSE because the grades I'd achieved throughout the year were really good, but the GCSE comes with an exam. I didn't want to take the exam because I'm not very good at them. I liked the idea of doing the coursework while learning IT at the same time.

THAT ONE PARENTS' EVENING HAS LED YOU TO STUDYING COMPUTER SCIENCE AT COLLEGE AND UNIVERSITY. WERE YOU INTERESTED IN IT AT THE TIME?

I had an interest – like everyone does at that age – in video games, consoles, stuff like that, but I didn't own a computer or laptop until Year 10.

YOU ENDED UP WITH A MERIT. HOW DIFFICULT DID YOU FIND THE BTEC?

The BTEC wasn't that difficult. I was a bit shocked with the merit result because it involved a lot of writing, which was kinda boring – and there wasn't any programming. The GCSE might have been better for me, but this course hasn't stopped me from getting where I am today, so I don't regret it.

WHAT SUBJECTS DID YOU TAKE AT COLLEGE?

I retook English Language and did the Level 3 IT Extended Diploma. For the Diploma, I came out with triple distinction star, which filled me with a lot of confidence.

LEAVING HOME

WHY DID YOU CHOOSE TO GO TO UNIVERSITY?

I wasn't going to go to university. The college workload was pretty heavy, so I wanted to take a break. I knew university was going to be expensive; it meant moving away; and I didn't feel quite ready for it. But mum was having none of that.

My tutor at college said: 'You might as well strike while the iron's hot. If you've got the motivation for it you should try and go for it.' It was a bit after the UCAS deadline to sign up for the course when we [Niall and his tutor] started scouting around for degree courses that were actually going to push me – because the ones I'd taken previously hadn't. When we got in contact with Martin, the course leader at UWE, he was keen to take on more people, so I decided to go for it. It seemed like the right choice.

WHAT DO YOU LIKE MOST ABOUT THE COURSE?

I like how it's not just focused on one area. Some days you'll be working on web design, and on other days you're programming a robot to follow a line. I went to uni with very little programming experience and now I'm basically learning entire new computer programming languages – not just one but five or six.

IS THERE ANYTHING YOU DON'T LIKE?

In the first year, they give you information brick by brick, and build on it. Now, in the second year, they're not giving us bricks, they're giving us walls and houses to put up. I suppose I should be taking more notes. I guess that's what more committed students do.

DO YOU HAVE TO BE A CERTAIN TYPE OF PERSON TO STUDY THIS COURSE?

No, as long as you're dedicated and happy with it, you can be any type of person. You can be the laziest person in the world, and sit in your bed, and you'll still make something good out of it.

LIFE AFTER UNI

WHAT DO YOU WANT TO DO WHEN YOU LEAVE UNIVERSITY?

I want to do something I'm going to enjoy. Something that pays OK so I'm not scraping around for the rent each month. If MI5 or GCHQ have departments that need computer security, or embedded systems, that's something I'd like to look into in the future. My dad is really passionate about that. He said I could be the next Q in James Bond.

ARE YOU SAYING THE WORLD IS YOUR OYSTER?

That's the picture that has been painted for us at uni – that there aren't really many limitations. I think the tutor said that 98 per cent of students he had last year were employed as soon as they left university because of their placement year [in the third year, students can choose to work in a company]. The good thing about a career in computing is that you can live in your dream location and still work for anyone in the world.

JOSHUA J DAYMUDE

PhD in Computer Science
Arizona State University, USA

CURRICULUM VITAE

35+ academic courses in high school, all at grade A
STEM courses include:
- Maths: algebra II / trigonometry, pre-calculus, statistics, AP Calculus BC, multivariable calculus
- Science: biology, AP Chemistry, AP Physics A, AP Physics B
- Computer Science: programming in C

BS in Computer Science and Mathematics, Arizona State University

WILL THIS BE THE RESEARCH SCIENTIST THAT HELPS GOOGLE OR MICROSOFT SOLVE REAL-WORLD PROBLEMS IN COMPUTER SCIENCE?

A PHD STUDENT IN COMPUTER SCIENCE AT ARIZONA STATE UNIVERSITY, JOSH HAS ALREADY APPLIED HIS SKILLS AT GOOGLE AND A HIGH-TECH START-UP. AS AN INTROVERT, HE TELLS US HOW HIS STUDIES AND LOVE FOR SHARING IDEAS HAVE HELPED HIM GROW INTO AN EFFECTIVE COMMUNICATOR AND ATTRACTIVE JOB CANDIDATE

YOUR GRADES WERE REALLY GOOD AT SCHOOL. HOW DID YOU DO IT?

My parents always supported and encouraged me and my siblings, which played a big role in honing any natural aptitude I had into good grades. My mum instilled in us an extreme attention to detail and care in our work. As a family, we always celebrated our successes.

WHY DID YOU DECIDE TO STUDY COMPUTER SCIENCE AND MATHEMATICS AT ARIZONA STATE UNIVERSITY?

In my last year of high school, I did an online maths and programming course, which was pretty fun. I had a family friend who was doing an undergraduate degree in computer science and he invited me to stay with him at his college for a couple of days. That was hugely impactful for me – I had never been on a college campus before. He took me to his classes and showed me around. To be honest, had he been studying biology, I probably would've ended up a biologist! That personal connection was really important to me and I felt very comfortable in starting my own undergraduate degree in computer science and maths.

Arizona State University offered me a scholarship, which enabled me to finish my undergraduate degree with a minimal amount of debt. This gave me a lot of freedom to do what I wanted after graduating.

WHAT DID YOU LIKE ABOUT YOUR UNDERGRADUATE DEGREE?

What I loved about Arizona State University was that while you were never forced to excel or go above and beyond, there were always the resources to help you do so if that's what you wanted. There are opportunities for internships, student organisations and clubs, and I learned a lot about jobs in different areas of tech, other cultures, and much more.

Computer science suits me well. I like things to make sense and I like order. Computer science allows you to evaluate whether something could be made more simple, elegant and understandable to people.

I also really enjoyed the maths. I took an introductory class in theoretical maths with a group of friends and there was something wonderful about doing it as a group. If I was stuck, someone else wouldn't be and so we helped each other out. Teaching each other also helped us to get a better grasp of the subject.

WHAT MADE YOU STAY ON AT ARIZONA STATE UNIVERSITY TO DO A PHD?

Towards the end of my undergraduate degree, I still hadn't decided what to do next. I found computer science and maths fun, and I knew that I was good at them. These subjects lit me up in a way that other fields didn't seem to. I did my undergraduate research project with Prof. Andréa Richa, and she was a big driving force in my choice to apply for a PhD (See p52: "The superpowers of swarms").

Beyond just being able to continue my research, there's also a personal side to the story. At the time, my girlfriend, Annie Carson, was starting her Master's in Public Health at Emory University in Georgia. So, when Andréa said that she was collaborating on a research

> TO CREATE TOOLS THAT GENUINELY BENEFIT ALL OF US, WE NEED THE BEST OF US WORKING ON THESE PROBLEMS, AND THERE'S NO REASON WHY THE BEST OF US SHOULDN'T INCLUDE PEOPLE OF EVERY GENDER, BACKGROUND AND NATIONALITY.

project with Georgia Tech and that I could go and visit Annie every couple of months, it sealed the deal! Not all decisions have to be made according to prestige or a career path – personal happiness is important, too. Annie and I are now married, so we're both sure I made the right choice!

ARE YOU GLAD YOU DECIDED TO DO A PHD?

Yes! Most PhD programmes are like apprenticeships, in a way, which you don't get when you start a job. You have support from an incredibly expert and brilliant educator whose only interest is to make you good at what you do! There's a lot of comradery in our lab because everybody is so invested in everybody else's successes.

There's also a lot of freedom and flexibility in a PhD. If you can be personally responsible for your own research, you can work at your own pace and be in control of your schedule. This freedom has allowed me to explore new opportunities and experiences, such as teaching and investigating new problems.

It took me a while to realise that no one can know everything, and results and successes are not always proportional to the amount of time you put in. You have to get really comfortable with "being lost at sea" – no one has solved these problems before!

WHAT OPPORTUNITIES ARE AVAILABLE TO YOU WITH A PHD IN COMPUTER SCIENCE?

As I see it, there are four different options. You can become a professor, which involves supervising students, teaching, doing research – all of which fits in well with what I'm doing now. Alternatively, the skills you learn with this PhD apply well to high-tech careers. For example, there are plenty of research-orientated jobs in big tech companies such as Google or Microsoft. Or, the kind of interdisciplinary research [i.e. combining two or more academic subjects] that I'm doing in my PhD would fit well in a start-up company. Finally, there are plenty of positions in government in advisory roles, such as informing policy or building secure computer infrastructure.

Each summer, I 'try out' one of these options by working part-time on my research and doing an industrial internship – for example, with Google. This summer, I'm going to work at a start-up. It's good to try different things and a PhD gives you the flexibility to do that.

THERE AREN'T MANY GIRLS IN COMPUTER SCIENCE. WHAT CAN WE DO ABOUT THIS?

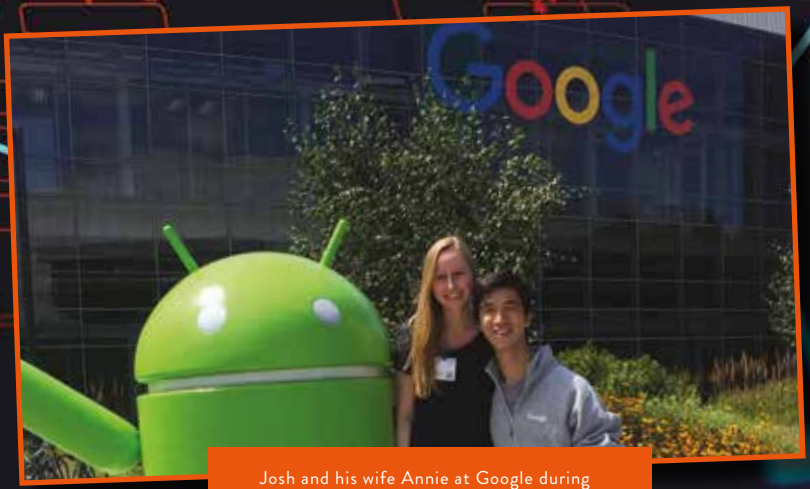
The purpose of STEM fields is to make discoveries, create advances and develop tools to better all of humanity. To create tools that genuinely benefit all of us, we need the best of us working on these problems, and there's no reason why the best of us shouldn't include people of every gender, background and nationality.

It's vital that we commit to making STEM fields more welcoming, inviting and supportive than they have been in the past.

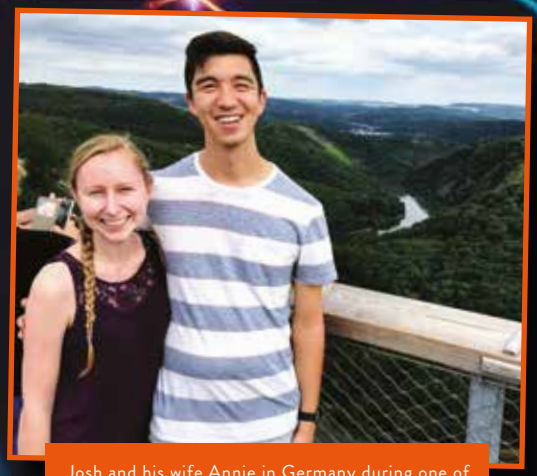
YOU SAY YOU'RE AN INTROVERT. IS COMMUNICATION IMPORTANT IN COMPUTER SCIENCE?

As an introvert at high school, computers were a bit of a refuge for me. They rely on rules and logic, which I find comforting. However, as a PhD student, I've realised how important it is to communicate your ideas clearly, and this definitely requires some social skills. You can be the most brilliant person and have some awesome ideas, but if you can't explain them to people, it becomes very hard to be successful.

I learned to be a social introvert. If there's something that you really care about, the only real way to make that matter to other people is to talk to them and be compelling. Being an introvert is certainly not a roadblock to success in this field.



Josh and his wife Annie at Google during his industry internship



Josh and his wife Annie in Germany during one of his research trips

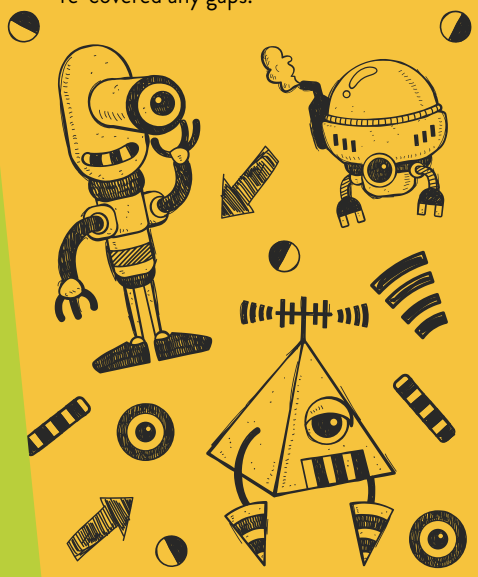
THE SUPERPOWERS OF SWARMS

SOME ANIMALS ARE CAPABLE OF PRETTY AMAZING FEATS WHEN THEY GET TOGETHER. ANTS, BEES AND FISH MAY APPEAR TO BE SIMPLE CREATURES, BUT THEIR COLONIES, SWARMS AND SCHOOLS DISPLAY COMPLEX BEHAVIOUR. COMPUTER SCIENTISTS LIKE **DR ANDRÉA RICHA** ARE TAKING INSPIRATION FROM NATURE TO CREATE SWARMS OF ROBOTS THAT CAN PERFORM DANGEROUS TASKS AND SAVE LIVES

IMAGINE THIS

The Forth Road Bridge is a 2.5km-long suspension bridge spanning the Firth of Forth in Scotland. It's a distinctive local landmark. More than 200,000 square metres of red paint protect its steel from corrosion. Every square centimetre of paint, as well as electrical cables and tens of thousands of bolts, are checked as part of a maintenance programme that never ends. The inspection team braves heights and bad weather to keep the bridge open.

Imagine if the inspection crew were a swarm of miniature robots with orders to repair any damage, and the paint was made of programmable matter that automatically re-covered any gaps.



What happens when army ants come across a big gap in front of them? They could take the long way around, following the edge of the crack until they can get around it. But they don't – they make their own short cut. The ants that encounter the gap build a bridge out of their own bodies. Those following behind then walk over the bridge to reach the other side.

How do these ants know what to do? You might think that the queen ant sends out instructions but that's not what happens. No leader directs the bridge-building task. Instead, each ant acts on its own, following simple rules. The combined effect of every ant following the same set of simple instructions produces a remarkable outcome. Together, they build a bridge.

Other types of ant display equally remarkable behaviour. Fire ants escape flooding by collecting themselves into a waterproof raft that can float on water. Again, each ant follows simple instructions to produce a flat, floating structure. This behaviour is called "swarming".

In mathematics, a set of instructions is known as an algorithm. Investigating the algorithms that produce the kind of complex behaviour seen in ants, bees and fish is the focus of work by Dr Andréa Richa and her colleagues. She's based at Arizona State University's School of Computing, Informatics and Decision Systems Engineering.

In computer science, self-organising particle systems (SOPS) can be described as human-made swarms. SOPS are studied through computer simulations and formal proofs, but the ultimate goal is to produce a real swarm made of robots. And with the right algorithms, we could get these robots to perform all sorts of useful tasks.

WHAT ARE SELF-ORGANISING PARTICLE SYSTEMS (SOPS)?

Self-organising particle systems (SOPS) consist of a multitude of tiny particles that work together to produce a particular behaviour on a larger scale. The particles are very simple, small robots that are all given the same basic instructions, or algorithm. Even though there's no leader telling the system what to do, these basic instructions result in complex behaviour – like a group of ants building a bridge.

WHAT WOULD SOPS BE LIKE IN THE REAL WORLD?

Imagine if you could produce a material made up of thousands of separate pieces – all identical. All the individual pieces would move around together, so it would seem to be a single lump of material. This is the idea behind programmable matter. Let's say something fell on the material and a crack appeared. Instead of staying damaged, pieces of the material would move together to close the crack. The material could also be used as paint. But instead of using a brush, you might throw the material at a wall and it would spread itself to cover the surface. Other materials might change shape in response to a particular sound. These are just a few of the possibilities, and the study of SOPS is a first

Find this article online and download the activity sheet: https://futurumcareers.com/the-superpowers-of-swarms

DR ANDRÉA W RICHA

Professor, School of Computing, Informatics and Decision Systems Engineering, Arizona State University, USA

FIELD OF RESEARCH

Computer Science and Engineering

RESEARCH PROJECT

Andréa's research focuses on algorithms and how they might control self-organising particle systems (SOPS). These algorithms program the SOPS to mimic swarming behaviours seen in nature. https://sops.engineering.asu.edu

FUNDER

National Science Foundation

step towards making programmable matter a reality.

WHAT COULD PROGRAMMABLE MATTER BE USED FOR?

There are plenty of jobs in the world that are extremely dangerous, like defusing bombs or fixing leaks in a nuclear power station. Other jobs might be less dangerous but cost a lot of money. Large structures like aircraft, ships, buildings and bridges must be properly maintained to keep them safe. Such maintenance needs large teams of people and takes a long time. The maintenance team has to be on site and equipped with specialist tools and devices for taking measurements and performing tests.

In the future, jobs like these could be done by a smart material instead of people. The smart material would comprise tiny sensors, each capable of moving around. On a bridge, sensors could detect and measure the temperature, traffic load, and structural cracks and stresses. If they were also equipped with a container and a nozzle, they could squirt glue-like material into fractures to repair them.

Smart materials may also go where human beings cannot. For example, a crack on the outside of the International Space Station could be catastrophic to the astronauts inside. Instead of an astronaut putting their life at risk by going outside on a spacewalk, a collection of tiny sensors could set off on a repair mission. You can imagine a blob of material crawling around the outside of the space station until it found the crack and fixed it.

HOW COULD SELF-ORGANISING PARTICLE SYSTEMS SAVE LIVES?

One day in the future, you might look up and see a swarm of robots repairing a building or a bridge. But it may be possible to create sensors as small as molecules – small enough that they could travel around inside your body. If you're not feeling well, a doctor could give you millions of these sensors to swallow. It might look like an ordinary pill. But inside your body, they would split up and find their way around the blood system until one of them identifies something that doesn't look right. Without any further instructions, the first sensor to find a foreign body could tell the others to come and join it. Perhaps they would then surround the invader or send a signal showing the doctor where to find it. If this idea is ever put into practice, it could be a very effective way of stopping internal bleeding or detecting cancer.

WHAT ARE THE ADVANTAGES OF SELF-ORGANISING SYSTEMS?

Self-organising systems have two advantages over a single robot. One advantage is that they're less prone to failure. With many tiny computation devices, it doesn't matter if a single device goes wrong. The system will continue operating as before. Think of an ant colony: an individual ant can be replaced by another because they're all the same. The other advantage is that it can easily be scaled up if you need a bigger system: for example, to find cracks on a larger bridge. Each individual robot or sensor is very simple, so it's cheap and easy to add more.

WHEN WILL WE SEE SELF-ORGANISING SYSTEMS BEING USED IN THE REAL WORLD?

For SOPS to become a reality, several major problems need to be tackled. One is developing physical robots. Each individual particle needs to be designed and engineered so that they can be produced cheaply, quickly and efficiently – thousands at a time. Once we have physical robots, they need to be programmed so that each follows the same simple rules. That's where Andréa and other scientists are involved, developing the algorithms that the particles will each follow to produce the desired collective behaviour.

ABOUT COMPUTER SCIENCE AND ENGINEERING

Every time you use a laptop, phone, set-top box or smart speaker, you're using some kind of computer. The physical parts of a device, including its circuitry and microprocessors, are designed by computer engineers. Whereas the computer code that operates it, the software, is created by computer scientists. The pace of change in computing is rapid, with microprocessors getting smaller, robots more commonplace and software more intelligent. This will usher in a new wave of smart technology to improve the running of hospitals, offices, factories, shops, concert halls and cars.

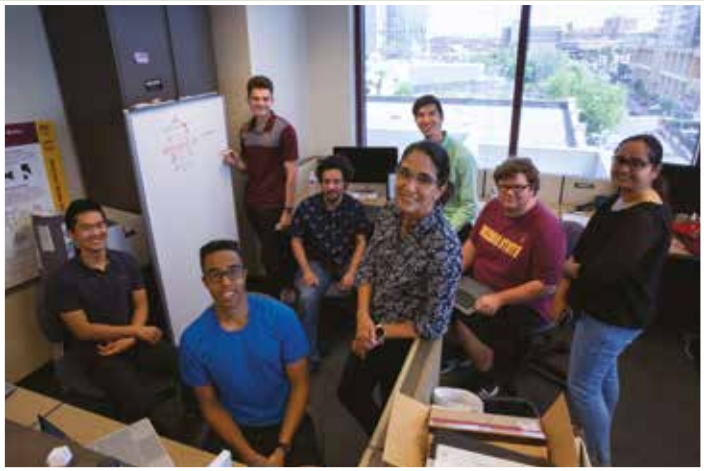
The people who'll shape this future – computer scientists and engineers – have analytical minds. They use creativity and problem-solving skills to get systems up and running. Most will have studied maths and a science subject – often physics - before taking a computer science degree at university.

OPPORTUNITIES IN COMPUTER SCIENCE AND ENGINEERING

- Google's Computer Science Summer Institute helps aspiring computer scientists learn programming fundamentals and develop their own apps. It's a three-week programme open to students who have already enrolled on computer science courses in the US and Canada.
- Microsoft University Internships are open to students around the world who have enrolled full-time as students majoring in a suitable field. Opportunities range from software and hardware engineering to UX (user experience) design and data science.
- The average salary of a computer scientist in the US is just over $100,000 per year, according to Indeed.com. But the range of jobs varies enormously, and experienced professionals can earn twice as much. The average starting salary is about $65,000.

ANDRÉA'S TOP TIPS

- Work according to your goals and your capabilities.
- Sometimes you'll find a particular subject difficult but that doesn't mean you can't succeed, even if it takes you more effort than someone else.
- In many places, computer science is a male-dominated profession, which may put some potential students off. Universities and workplaces now have structures in place to give you extra support if you feel like you're in the minority.
- Women can succeed and be happy in a male-dominated area – in fact, until recently, I had more female PhD students than male!



Andréa and her SOPS team of PhD, Masters and undergraduate students

ASK DR ANDRÉA RICHA

WHAT DID YOU WANT TO BE WHEN YOU WERE GROWING UP?

I didn't know exactly, but I knew it had to be something related to maths. It was my favourite subject in school. My mum was a maths professor so I'm guessing she passed on some maths-loving genes to me! I love logical thinking.

WHO OR WHAT INSPIRED YOU TO TAKE UP A CAREER IN COMPUTER SCIENCE?

I didn't want to just study maths when I went to university. Computer science was a new field at the time, at least in Brazil where I grew up, and it felt exciting. I found that I liked some classes but not all. Pure programming was just not for me, and I was thinking about switching to pure maths until I learned about algorithms.

WHAT DID YOU DO AFTER UNIVERSITY?

I knew I wanted to carry on studying algorithms, so I carried on with my Master's degree in Brazil. Algorithms ultimately lead to computer programs but they're more abstract. I was interested in the logic behind them, and why some problems are easier to solve than others. After my Master's, I wanted to experience living abroad so I pursued a PhD at a university in Pennsylvania, USA.

WHAT DO YOU LIKE ABOUT WORKING IN A UNIVERSITY?

The nice thing is that you can always change direction. Even if you're working on something that becomes boring, you can always move to a different area of study. There are always new things coming up so it's very dynamic. For me, I like the idea of picking up new research areas that I can work on. And I love working with students.

WHAT ELSE DO ENJOY BESIDES MATHS?

I sing in a university choir and I like cycling, skiing, hiking, and travelling. I'm a pretty sociable person. I love going out with my friends and family, and going to movies with my kids at the weekends.

Andréa working on a problem with her PhD student Josh Daymude

Andréa in front of a picture from the group's prototype 3D SOPS simulator

ABOUT JOHN VOLANTHEN

CEO, Hub Network Services

Cave Rescue Diver, Cave Rescue Organisation, South and Mid Wales Cave Rescue

"As CEO, I ensure the company is moving in the right direction, both from an organisational point of view and also from a technology perspective. It's about ensuring we deliver the best solutions for customers to meet their needs both now and in the future."

WORLD RECORDS

Deepest British cave dive, completed with Richard Stanton in 2004

Longest cave dive, completed in the Pozo Azul caves, Spain, with Richard, Jason Mallinson and René Houben in 2010

AWARDS

Royal Humane Society award for the rescue attempt of a diver in a French cave, 2012

Bronze Cross, The Scout Association's highest honour, awarded for the Thai cave rescue, 2018

Pride of Britain for 'Outstanding Bravery', awarded for the Thai cave rescue, 2018

ABOUT HUB NETWORK SERVICES (HNS)

HNS is primarily an internet services and connectivity provider. The company delivers connectivity solutions to businesses. These involve connecting large numbers of sites together, sometimes to the internet, data centres and/or cloud services – usually a combination of all three.

THINK COMPUTER SCIENCE IS FOR NERDS? THINK AGAIN!

JOHN VOLANTHEN, CEO AND COMPUTER CONSULTANT, WAS ONE OF THE DIVERS WHO RESCUED THE FOOTBALL TEAM IN THE THAM LUANG CAVE, THAILAND. HE TELLS US WHY THERE'S MORE TO A JOB IN COMPUTER SCIENCE THAN CODING

YOU STUDIED ELECTRONICS AT DE MONTFORT UNIVERSITY. WHY ELECTRONICS?

I chose electronics originally so as not to end up spending my life behind a screen. The world has changed considerably since then. I have found the discipline used in electronic design has helped me immensely, along with the experience I gained during work experience and my first job after university.

SO, HOW DID YOU TO GET INTO COMPUTING?

By chance! I ended up in a house with three computer scientists in my second year at university. We also had programming lessons in assembler (ASM) and Pascal [computer programming languages]. With the help of my house mates, I made good progress and found I could conceptualise data and program flows.

My degree had a sandwich year in work [sandwich courses are degrees that involve a year working in industry]. I spent a year at Great Ormond Street Hospital in the medical electronics department. At that time, interfacing computers to medical devices was a relatively new idea. While working there, and through my subsequent years of employment, I found I had a flair for developing software and interfaces. I also studied for and gained an MSc in information systems design.

Later, I worked for a small internet services provider and decided I could do a better job. Out of that, HNS was born.

YOUR INTEREST IN CAVING STARTED WHEN YOU WERE A SCOUT. WHAT WAS IT ABOUT CAVING THAT DREW YOU IN AT SUCH A YOUNG AGE?

I have always liked the balance or difference between a physical hobby such as climbing, caving or running, and being inside, nice and dry and warm. Caving presents physical challenges to overcome and enjoy – plus it allows teams to get to know each other much better than through sports such as football.

I still take scouts caving today.

HOW DID YOU GET INTO CAVE DIVING?

Scouts get to free dive short sumps (flooded cave sections) in a safe manner, with no breathing apparatus. At various points in my caving career the leaders would point to a loner sump and declare it "impossible". That was undoubtedly the seed for me. I don't like to think of things as impossible – I want to ask "how?".

WHAT ABOUT CAVE RESCUE DIVING? HOW DID YOU GET INTO THAT?

I'm not sure anyone chooses to go into cave rescue diving. In the UK, at least, cave rescue is voluntary, and local cave rescue groups look to the cave diving group to provide support for rescues as and when it is required. I have been involved in a number of incidents over the years, some with happy endings, most not.

Rescues of non-divers are very rare events, and always an absolute last resort due to exceptionally high risks for both the rescuer and the casualties. Normally, this type of specialist rescue involves the body recovery of cave divers who have encountered difficulties of some sort or another and drowned. Tham Luang was the exception.

John explores the Rinquelle Resurgence cave in Switzerland.

YES, YOU WERE PART OF THE RESCUE TEAM THAT SAVED 12 YOUNG FOOTBALLERS AND THEIR COACH TRAPPED IN THE THAM LUANG CAVE IN THAILAND. WERE YOU SCARED AT ANY POINT?

The diving conditions at Tham Luang were well within our capabilities, although there were some specific difficulties that required great respect – the low visibility, and the complexity and size of the passage in places needed concentration. The scary part was taking another human life from a relative place of safety, placing them directly in harm's way and being solely responsible for their survival.

WHAT WAS THE HIGHLIGHT OF THAT RESCUE MISSION?

The success rate was unexpected. Given the difficulty of the mission, to achieve 100% success was almost unbelievable. It is very hard to explain to non-cavers why the children could not remain in the cave but, writing this now in December, the water level in Tham Luang still hasn't dropped enough to walk out.

YOU MENTIONED IN AN INTERVIEW WITH THE BBC THAT CAVE DIVING "IS VERY CALCULATING, VERY CALM". DOES IT HELP TO HAVE A HEAD FOR MATHS?

Maths helps with diving to some degree, but I think the real key is problem solving – being able to look at all the variables of a situation, make a sensible rational decision and follow it through. I liken this to the old problem with the chicken, the fox and the grain, and how to get them across the river – Google it!

A TYPICAL STEREOTYPE OF SOMEONE WORKING IN COMPUTERS IS THAT OF A NERD WITH TERRIBLE SOCIAL SKILLS. WHAT DO YOU SAY TO THAT?

I might have agreed with you 25 years ago, but not today. Good computer scientists require a very different mindset and understanding than just playing games. All businesses need highly competent IT teams and individuals, all the way up to board level [top management]. These people, male and female, employ a raft of skills, including communications, finance and many others.

FINALLY, WHAT ADVICE DO YOU HAVE FOR YOUNG PEOPLE WHO ARE CONSIDERING A CAREER IN COMPUTING, BUT ARE A LITTLE UNSURE WHETHER COMPUTER SCIENCE IS FOR THEM?

Computer science offers not just a grounding in traditional programming, but also in structured thinking – and now offers a career path from a coding job all the way to the boardroom.

"COMPUTER SCIENCE OFFERS NOT JUST A GROUNDING IN TRADITIONAL PROGRAMMING, BUT ALSO IN STRUCTURED THINKING - AND NOW OFFERS A CAREER PATH FROM A CODING JOB ALL THE WAY TO THE BOARDROOM"

THE TINY ANIMAL AT THE CENTRE OF THE MARINE ECOSYSTEM

PROFESSOR MARC FRISCHER, FROM THE UNIVERSITY OF GEORGIA'S **SKIDAWAY INSTITUTE OF OCEANOGRAPHY**, IS INVESTIGATING TINY OCEAN CREATURES KNOWN AS DOLIOLIDS AND THE FOOD THEY EAT. WHY? HIS RESEARCH CAN HELP US UNDERSTAND THEIR ROLE IN OCEAN FOOD WEBS AND THE IMPACT CLIMATE CHANGE COULD CAUSE

WHAT'S EATING WHAT IN AN OCEAN FOOD WEB?

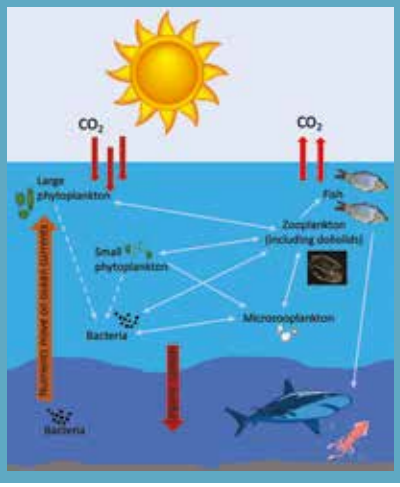
Phytoplankton use energy from sunlight and nutrients dissolved in the water to convert CO_2 to organic carbon. This forms the base of the marine food web – the cycling of matter and energy.

Phytoplankton are eaten by microzooplankton and zooplankton, which provide a food source for fish, which in turn feed the larger predators such as squid and sharks. Nutrients associated with phytoplankton that are not consumed by larger organisms are decomposed by bacteria.

Most of the carbon is converted back into CO_2 and released into the atmosphere, but some is transported into the deep ocean where it can be stored for hundreds to thousands of years.

The structure of the food web and the abundance of each species will control how much carbon is transported to the deep ocean.

Figure modified from Chisholm, S.W. (2000). Stirring times in the Southern Ocean. Nature. 407, 685-687. doi: 10.1038/35037696



Most people have never heard of, let alone seen, a doliolid, but these tiny creatures play a critical role in the marine ecosystem. So much so that Marc Frischer, a professor from the University of Georgia's Skidaway Institute of Oceanography, and his team are investigating them, their eating habits and the role they play in ocean food webs.

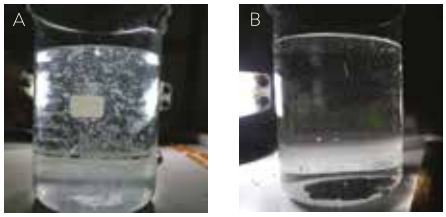
Ranging in size between one and 15 millimetres (depending on the stage of their complex life cycle), doliolids are small, transparent and barrel-shaped. These gelatinous marine animals live on the continental shelves all over the world. Continental shelves are the shallow parts of the ocean that surround the continents and are some of the most productive regions of the ocean. Even though continental shelves only occupy 7-8% of the ocean area, half of all ocean productivity – when plants and bacteria produce energy for the rest of the ecosystem to use – occurs here.

Doliolids are a type of zooplankton, a group of small animals that drift around in the water. Although most zooplankton are tiny, there are so many of them that by weight they're the most abundant type of animal in the ocean.

WHY IS IT SO IMPORTANT TO STUDY DOLIOLIDS?

Marc studies doliolids because they eat microbes. Microbes are tiny life forms, including bacteria, phytoplankton, viruses and fungi, that surround us everywhere. Without them, we wouldn't be around to study them. "I've always been interested in figuring out how microbial communities in oceans interact with larger organisms as well as the planetary-scale cycling of matter and energy, all of which helps to maintain balance in our marine ecosystem," says Marc.

Doliolids are particularly fascinating because their numbers vary greatly. Sometimes there is



The abundance of doliolids varies greatly: these samples were collected from the same location about 2 weeks apart. A: > 20,000 doliolids per cubic meter of seawater, B: < 10 doliolids per cubic meter of seawater.

an abundance of them; at other times there are hardly any (see above). Because these changes in the doliolid population are unpredictable, their impact on the ecosystem's food web is complicated and difficult to understand.

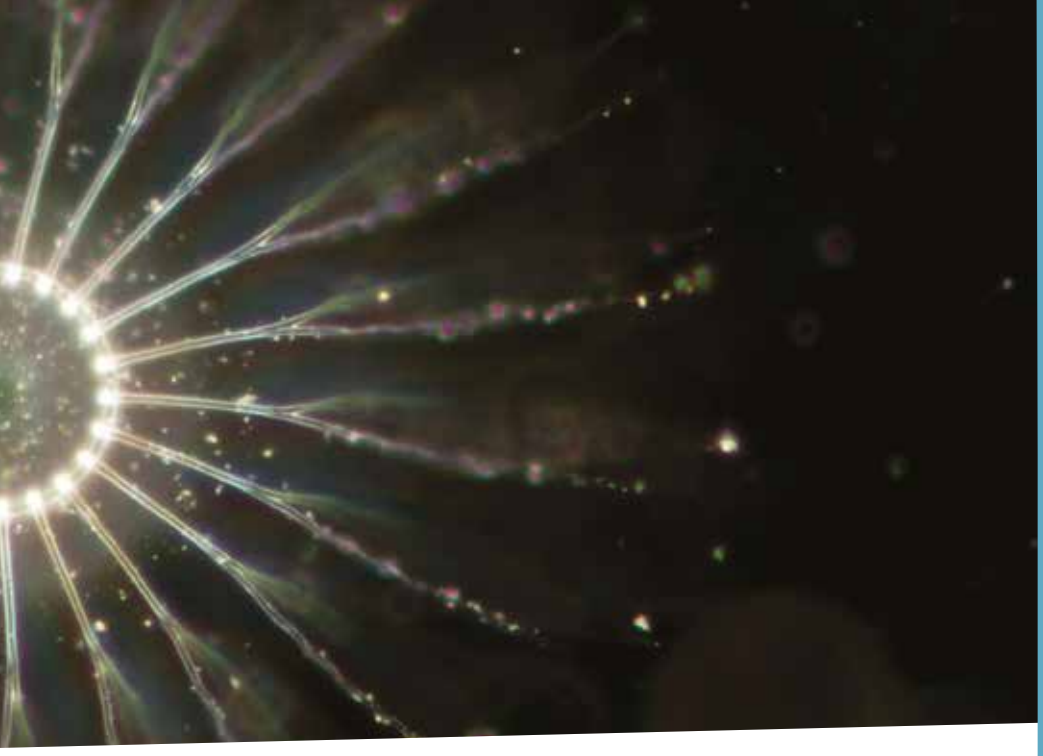
Because doliolids can be so abundant in productive continental shelf environments, understanding what they eat, how much they eat and ultimately who eats them would provide some hints on how they're involved in balancing the marine ecosystem.

IF WE KNOW DOLIOLIDS EAT MICROBES, WHY IS MARC STUDYING THEIR DIET?

It's known that doliolids are able to eat algae, other microbes and small zooplankton that fit in their mouths, which means their eating habits have a large impact on life in the ocean. But because doliolids are so small and fragile, it's very hard to study them. As a result, scientists aren't exactly sure what and how much they eat.

Microbes dominate life on our planet, and the question of how they interact with the environment and larger organisms remains one of the most important mysteries: how do complex, modern ecosystems such as the ocean work? "Although we understand with some certainty that the climate is changing,

Find this article online and download the activity sheet: https://futurumcareers.com/the-tiny-animal-at-the-centre-of-the-marine-ecosystem



PROF MARC FRISCHER

Professor of Oceanography
Skidaway Institute of Oceanography
University of Georgia, USA

FIELD OF RESEARCH

Biological Oceanography

RESEARCH PROJECT

Marc and his team are studying doliolids and the food they eat. Through his work, Marc hopes to understand the critical role doliolids play in the marine ecosystem, and how their existence is threatened by climate change.

FUNDERS

The US National Science Foundation, the US National Oceanic and Atmospheric Administration, the US Department of Energy, and various other US State and National funding agencies

and that the oceans of the future will likely be warmer, more acidic and contain less oxygen," says Marc, "it's very difficult to make specific predictions about the impacts of climate change, especially on larger organisms such as fish, whales and humans." Doliolids connect microbes with larger organisms, so knowing their role in marine foods webs will help marine scientists – and us – understand and prepare for the consequences of future ocean changes.

HOW DOES MARC'S TEAM STUDY DOLIOLIDS?

Marc and his colleagues have been studying doliolids in the ocean and in the lab, but it's not easy. Doliolids are small, transparent, delicate creatures, so they're hard to count, catch and grow. Indeed, doliolids are so delicate that standard nets damage them. Marc uses a special plankton net to capture doliolids (take a look at the photo on the bottom of page 60).

Interestingly, other researchers are studying doliolids without even capturing them. Rather, they're taking videos of these delicate creatures in the ocean, and processing these images using powerful computer analysis tools. "I think these tools will eventually lead to exciting new discoveries about doliolids and the many other types of gelatinous organisms that are too delicate to capture using nets," says Marc.

HOW DOES MARC'S TEAM STUDY WHAT DOLIOLIDS EAT?

Inside their little, barrel-shaped bodies, doliolids catch food using a fine mesh that they create out of sticky mucus. The doliolids filter water through this mesh, capturing particles that can be as small as bacteria or as large as their mouth. Scientists think that the mucus is best suited to catching algae-sized particles.

In his lab, Marc first extracts all the DNA from a doliolid and then removes the DNA belonging to doliolids. This means that he's left with DNA that he presumes comes from the food they ate (or any parasites that may have come along for the ride). Using this technique, Marc has found that doliolids actually eat a lot of different foods, but they can sometimes be picky about what they eat! "We didn't expect this," he says. "It just adds even more mystery to the question of what they eat. As Albert Einstein is credited with saying: 'The hallmark of good research is that it raises more questions than it answers'. This is certainly the case with doliolids."

WHAT EATS DOLIOLIDS?

It's thought that lots of larger organisms eat doliolids, but scientists aren't exactly sure which ones. Some have suggested that important fish species such as plaice, tuna and marlin eat doliolids at some point during their lifespan, most likely when they're larvae or juvenile (i.e. very young).

Excitingly, Marc's studies on the continental shelf of the South Atlantic Bight, which runs along the US Atlantic coastline from Cape Hatteras in North Carolina to Cape Canaveral in Florida, has shed some light on this mystery: his team found that doliolids in this region were eaten by small jelly fish-like animals called hydromedusae.

HOW WILL CLIMATE CHANGE IMPACT DOLIOLIDS?

We know that doliolid populations vary depending on the amount of food that's available in the ocean. And the amount of food available to doliolids depends on how many nutrients (mainly nitrogen) make it from the deep ocean onto continental shelf, where doliolids are found. Currents push nutrient-rich water from the deep ocean onto the continental shelf, which allows algae to grow and, ultimately, provides doliolids with food.

A lot of different factors affect these currents, including wind patterns. Scientists expect climate change to affect wind patterns, but they're still uncertain about how much this will alter the availability of food for doliolids. Scientists also don't know whether other climate change impacts, such as higher temperatures, less oxygen and more acid in the oceans, will affect doliolids.

This is why the work of biological oceanographers such as Marc and his team is incredibly important: knowing what role doliolids play in food webs and the ocean ecosystem will help scientists to find a deeper understanding of the impacts of climate change – and we need more marine scientists like you to help!

ABOUT OCEANOGRAPHY

Oceanography is a broad field, meaning oceanographers can choose to work in a wide range of different topics: marine life and ecosystems, plate tectonics, the geology of the seafloor, and the chemical and physical properties of the ocean.

Marc is a biological oceanographer and has been studying the oceans for over 30 years. We ask him why it's important to study oceanography.

"The oceans are the life support system of our planet. Every other breath of air we breathe was produced by phytoplankton, the microscopic plants that grow in the ocean. The ocean serves as the primary thermostat for our climate. It's the biggest contributor to the planetary water cycle: it impacts where and when it rains, floods or dries out. The ocean generates massive storms and it sustains us. And yet, the ocean is remarkably understudied and, in many parts, still unexplored.

Most species on Earth reside in the ocean, many of them remaining to be discovered. In all likelihood, life originated in the ocean. Rather than argue "why" study marine sciences, I would argue that we must study the ocean and all the life in it. I believe that the survival of humanity depends on it."

OPPORTUNITIES IN OCEANOGRAPHY

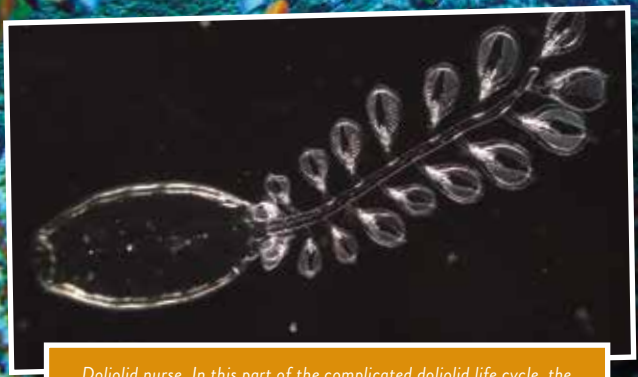
• Many organisations in the US (https://www.marinecareers.net/summer) and around the world (https://www.teensummercamps.com/collections/marine-biology/europe) host summer programmes that take high school students out onto the ocean to learn about what it's like to be an oceanographer

• World Oceans Day has a Youth Advisory Council and a Youth for the Ocean Network … get involved! https://www.worldoceansday.org/

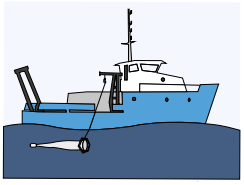
• There are so many opportunities open to graduates with a marine sciences degree. You can conduct research out in the "field" (the water), in a laboratory or both. You can teach at a university or work in a museum, aquarium or zoo. You can conduct research for the government or work for an environmental non-profit organisation, such as a marine animal rescue facility. The NOAA's National Marine Fisheries Service provides a good overview. For example, you don't need a PhD to work on marine biology experiments, but a PhD will allow you to run your own expeditions and come up with your own experiments

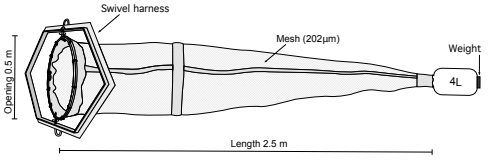
• According to the US Bureau of Labor and Statistics, the average university-employed marine scientist makes about $98,560 a year, but the salary can range widely depending on your education and experience

Doliolid gonozooid. This is the most common life stage found during blooms.



Doliolid nurse. In this part of the complicated doliolid life cycle, the barrel-shaped part of the animal has no organs except for a long tail.





Marc and his research team use a special plankton net to capture doliolids.

Find this article online and download the activity sheet: https://futurumcareers.com/the-tiny-animal-at-the-centre-of-the-marine-ecosystem

ASK PROF MARC FRISCHER

DID YOU ALWAYS KNOW YOU WANTED TO STUDY THE OCEAN?

Yes and no. From a very young age, I thought I'd follow in my father's footsteps and become a medical doctor. It was only as I was completing my undergraduate university studies that the reality of medical school and spending a large portion of my life in a hospital hit home. I decided that it wasn't for me, so I began to consider other possibilities.

WERE YOU GOOD AT SCIENCE AND MATHS AT SCHOOL?

I was okay, but not great at maths in school. Maths was hard for me and, frankly, I don't think I ever had a really good and inspiring maths teacher. I did have good science and history teachers, however. Those were my favourite subjects and I excelled at them.

WHAT OR WHO INSPIRED YOU TO STUDY OCEANOGRAPHY?

Growing up, I was always attracted to the water. Jacques Cousteau [the French naval officer, explorer and conservationist] was one of my heroes. I grew up far from the ocean in Chicago, in the middle of North America, but I tried to be around the water as much as possible. My family would spend summers on Lake Michigan, one of the largest lakes in the world, and I took a great interest in it. I swam competitively in school and I kept an aquarium of fish at home.

Marc and his research team wear iconic red Jacques Cousteau caps in honour of Marc's childhood hero

During high school, I had an opportunity to travel to the Middle East, where I had my first experience with saltwater, at the Red Sea. In hindsight, I believe an incident I had while exploring a coral reef in the Red Sea also inspired my interest in microbiology. Chasing fish about, I managed to scrape myself up pretty severely. At first, I didn't think much about it, just a few scratches, right? Wrong! Over the next few days, every one of those scratches became infected and I was truly miserable. Later, inspired by this experience, I did a little research and learned that corals are covered in a layer of bacteria-enriched mucus that helps feed and protect them from disease, UV exposure and suffocation.

I also learned that scientists didn't know much about the microbial communities that inhabit this slime layer. During university, I had an opportunity to spend a semester in the Caribbean studying marine management and biology. So, when I realised I didn't want to pursue a career in medicine, it didn't take too much soul searching to land on the idea of marine sciences and, in particular, marine microbiology.

WHAT DO YOU ENJOY MOST ABOUT YOUR JOB?

I love the creativity associated with identifying questions and designing studies to answer those questions. Most people don't think of scientists as creative, but scientists are some of the most creative and imaginative people. We have to be creative; it's our job to think up questions that have never been asked before. And, although it's true that "eureka" moments are very rare, when they do happen, they're thrilling!

MARC'S TOP TIPS

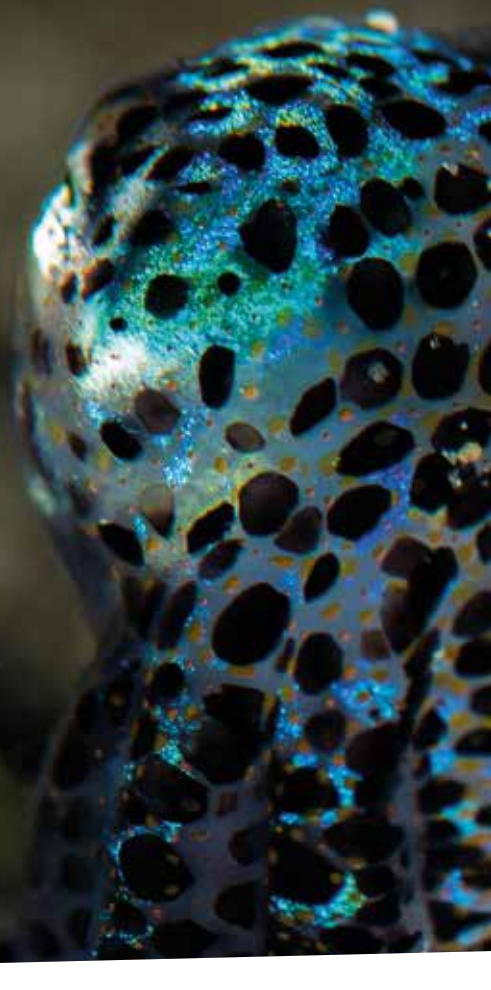
01 Don't specialise in marine biology too soon. If you're interested in the biology of oceans, make sure you have a strong foundation in biology, in general, and chemistry, physics, statistics, computer science, communications and, yes, even maths.

02 If you can, reach out to marine scientists though your school or a local university and explore extracurricular opportunities to participate in research projects. Or, perhaps take advantage of a marine-focused summer course or camp. But focus on the basics in school.

03 Meet people in the field and establish extensive professional and peer networks. The more people you meet, the more opportunities will come your way when the time is right.

WHAT CAN WE LEARN FROM BOBTAIL SQUID?

SARAH MCANULTY FROM THE **UNIVERSITY OF CONNECTICUT** IS LOOKING AT A VERY INTRIGUING RELATIONSHIP BETWEEN A BACTERIA AND BOBTAIL SQUID. WHY? HER WORK COULD TELL US A LOT ABOUT HOW OUR OWN IMMUNE SYSTEMS COMMUNICATE WITH – AND NEED – "GOOD" BACTERIA



SOME BACTERIA IS GOOD FOR US

There are "good" and "bad" bacteria. Of course, bad bacteria are those that make humans sick. But some bacteria are beneficial to humans; and without them, we wouldn't survive. They help us to digest our food and fight disease, for example.

Interestingly, many other animals cultivate beneficial relationships with bacteria, too. Imagine what we could learn from these relationships, and from studying the immune systems that regulate them. Could this knowledge help humans to boost their immune systems and better fight disease? What do you think?

SARAH'S TOP TIPS FOR GETTING INTO MARINE SCIENCE

1. Volunteer to help with animal care and conservation
2. At college, get involved with research as soon as you can
3. Carry a "don't give up" attitude with you throughout your studies and working life

The term 'symbiosis' describes the interaction between two different organisms living in close association. Oftentimes, these interactions are advantageous to both organisms and help them to survive. They may, for example, share their habitats or food. Or sometimes, the by-product of one organism's behaviour is beneficial to another.

Sarah McAnulty from the University of Connecticut has been studying an intriguing symbiotic relationship between a type of bacteria and the Hawaiian bobtail squid. She hopes to better understand their unique interaction and how the squid's immune system mediates it.

WHAT DO WE KNOW ABOUT THE HAWAIIAN BOBTAIL SQUID?

The Hawaiian bobtail squid (Euprymna scolopes) is found in the shallow waters of coastal Hawaii. The squid has amazing camouflaging abilities in that it's able to "disappear" as it swims through open waters at night. The squid's secret lies in a symbiotic relationship with a certain species of bacteria (*Vibrio fischeri*) that lives in its light organ.

HOW DOES THE CAMOUFLAGING SYSTEM WORK?

"The squid's light organ is a two-sided pouch that holds bioluminescent bacteria – *V. fischeri*," Sarah explains. "There is a filter that ensures the right colour light is emitted. There are even little areas of silver tissue that act like reflectors to control the light. All of that is surrounded by an ink sac."

How does this translate into open-water camouflaging abilities? Well, when the squid enters open waters to hunt at night, the bacteria emits a certain kind of light; in return for a sugary, amino acid solution. The light that *V. fischeri* emits is almost identical to the moonlight that is shining down on the squid from above. The result? The squid is virtually invisible to predators looking up from the seafloor. Sarah explains that this camouflage technique is known as "counter-illumination". I'm sure you would agree with Sarah when she says, "The symbiosis between *V. fischeri* and Hawaiian bobtail squid is super cool!"

HOW DOES THE SQUID SEEK OUT AND COLLECT *V. FISCHERI*?

Sarah admits that this is quite a challenging question to answer. There are incredible hurdles that the bacteria must overcome to find its way into the light organ. For example, they need to survive nasty chemicals outside the light organ, actively swim down special ducts, and then survive other internal chemicals on their journey to the light organ.

At this stage, it appears that the bacteria's success has something to do with the squid's

Find this article online and download the activity sheet: https://futurumcareers.com/what-can-we-learn-from-bobtail-squid

SARAH MCANULTY

PhD Candidate
Department of Molecular and Cell Biology
University of Connecticut, USA

FIELD OF RESEARCH

Marine Biology

RESEARCH PROJECT

Sarah's work aims to understand the symbiotic relationship between the Hawaiian bobtail squid and a bacteria that resides in its light organ, as well as the immune process that mediate this interaction. She is also the founder of Skype a Scientist, a unique initiative that links scientists with classrooms across the globe.

FUNDER (RESEARCH)

National Science Foundation

immune system. It can distinguish *V. fischeri* from other bacteria and reject the unwanted ones. "The squid has special immune cells called haemocytes," Sarah explains, "and when those haemocytes encounter a bacterium that shouldn't be there, they bind to the bacterium and then effectively eat it." However, that doesn't seem to happen in the case of *V. fischeri*. It's a pretty amazing immune system for a little squid that is a mere 3.5 centimetres in length!

HOW CAN THIS KNOWLEDGE BENEFIT HUMANS?

We know that we need good bacteria to strengthen our defence systems against disease. And yet, we still get infections and become sick. Why that occurs is the focus of many scientists' work. Sarah explains: "Scientists have been looking at how bacteria that make us sick at times remain undetected, or somehow overcome our immune system. We're now realising that it's way more complicated than that, and that our beneficial bacteria is "talking" to us all the time."

So, there's a lot to be gained from understanding the Hawaiian bobtail squid's symbiotic relationship with *V. fischeri*; especially the immune system processes that control it. Sometime in the future, we might be able to mimic the mechanisms the bobtail squid and other animals use to improve our very own immune systems and disease fighting capabilities.

OPPORTUNITIES IN MARINE BIOLOGY

- You could start by gaining employment or volunteering in an industry that works with animals, especially marine animals.
- In most cases, you'll need to do an undergraduate degree in science specialising in biology or marine science. Then you can branch out into marine biology at the postgraduate level. Check with your local universities to see what they offer.
- Some community colleges offer shorter, 2-year associate degrees in marine science, and these connect students with 4-year college degrees. The Southern Maine Community College, for example, offers such a course.
- More established marine biologists may earn from about $35,000 to about $80,000. The median pay, according to the Bureau of Labour Statistics, is about $62,000, but they lump marine biologists in with zoologists and wildlife biologists.

ASK SARAH McANULTY

DID YOU ALWAYS WANT TO BE A SCIENTIST FROM AN EARLY AGE?

When I was really young, I wanted to be a palaeontologist, but when I was about 8, I switched over to marine biology.

WHO OR WHAT INSPIRED YOU TO FOLLOW A CAREER IN MARINE BIOLOGY?

When I was a kid, my mom took me to the library ALL the time. There was this one video that was my absolute favourite. It was a *National Geographic Kids* video all about the ocean called "Really Wild Animals". There was a scene about halfway through that introduced the cuttlefish. I was immediately obsessed with cuttlefish and it's been that way ever since!

YOU'RE CURRENTLY A PHD CANDIDATE. WHAT DOES THIS MEAN?

That means that I'm in school studying to get a PhD. At this point, school really looks more like a full-time job than the school you might be familiar with now. I work in the lab, do experiments, process data, and then write it up and share it with people. I used to take classes, but I'm far enough along now that I don't have to take any more.

WHAT DO YOU HAVE TO DO TO BECOME DR SARAH MCANULTY?

I just need to write up my data, publish it, and then write my thesis. I've already started the finishing process, so I'll be Dr McAnulty some time in the summer.

WHAT DO YOU LOVE MOST ABOUT YOUR WORK?

I love feeding baby squid and sharing my squid and science with other people. Talking about science is one of my favourite things to do and getting other people excited about squid and marine biology gets me out of bed in the morning.

YOU HAVE CREATED A SPECIAL SCIENCE COMMUNICATION INITIATIVE CALLED "SKYPE A SCIENTIST". WHAT IS SKYPE A SCIENTIST?

Skype a Scientist is an initiative in which we match scientists with classrooms or groups of adults for 30- to 60-minute Q&A sessions about the scientist's area of expertise. It's really that simple. Teachers or other group leaders can request a scientist by filling out a Google form. Then they'll get their match within two weeks. Teachers can request a scientist from 24 different categories to match up with what the students are learning in class, and even request a scientist of a specific under-represented group so that students in the class see a scientist that looks like them.

HOW DID YOU COME UP WITH THE IDEA?

The idea came from an observation I made. I noticed a growing distrust towards science, both in the media and on the internet – it really seemed like a mess! In trying to understand why people weren't trusting science, I searched 'scientists' and the results were bleak – it wasn't very representative of the diversity in STEM that I've seen in my career. I figured if I could find a way to get real scientists talking to people then it may help the situation. I wanted to help people to know and trust real scientists. And the best way to do that is to just meet them! That's what Skype a Scientist is all about.

> *"I noticed a growing distrust towards science, both in the media and on the internet – it really seemed like a mess! I figured if I could find a way to get real scientists talking to people then it may help the situation."*

Sarah's Hawaiian bobtail squid

SKYPE A SCIENTIST

OVER 2,000 SCIENTISTS HAVE SIGNED UP TO SKYPE A SCIENTIST TO CHAT ABOUT THEIR WORK TO SCHOOL AND COLLEGE KIDS ALL AROUND THE WORLD. WHETHER YOU'RE A STUDENT OR TEACHER, FIND OUT HOW YOU CAN BOOK IN A SKYPE SESSION WITH ANY ONE OF THESE AMAZING PEOPLE

When you think about the word 'scientist', what comes to mind? Perhaps a certain type of person, wearing a certain type of clothing, doing something 'sciency'. But are your preconceptions about scientists correct? The truth is, scientists come from a whole range of different backgrounds, and they work in a whole range of interesting jobs. Related to this is a perceived disconnect between scientists and members of the public. Again, it's based on misconceptions – that scientists fit a certain profile and, in many cases, are unapproachable.

Sarah wanted to do something about this. She wanted to break down barriers between scientists and school students and open up dialogue between them. To achieve this goal, she created the so-called 'Skype and Scientist' initiative.

WHAT IS SKYPE A SCIENTIST?

Skype a Scientist is about connecting the lab to the classroom and encouraging students to get to know real scientists. Just imagine, you're sitting in class and on the projector screen – live in front of you – is a friendly, enthusiastic and knowledgeable scientist ready to answer your questions.

WHAT DO STUDENTS GET OUT OF SKYPE A SCIENTIST?

In addition to answering their questions, Skype a Scientist allows students to get a glimpse into life as a scientist. This is a notable feature because, as Sarah points out, "many of the examples of scientists in TV and movies are not particularly realistic, so seeing real scientist life can help folks decide whether science might be for them." So, students get some much-needed guidance. Perhaps it's the encouragement they need to reach out for a career in STEM.

Another benefit is that students, whether they're into science or not, learn to differentiate real science and scientists from the often-inaccurate representations in the media. This is an invaluable skill and helps us to make informed decisions about society. "Even if young people know they don't want to become a scientist, I think seeing what science is all about is really important for everyone, because it can dispel a lot of the myths about the science you may see on TV," says Sarah.

HOW DO YOU CONNECT WITH A SCIENTIST?

Teachers or other group leaders can request a scientist by filling out a Google form and then they'll get their match within two weeks. But Sarah also explained that students can contact Skype a Scientist directly. The only condition is that you a need a minimum of seven people to have a session.

WHO MIGHT YOU CONNECT WITH THROUGH SKYPE A SCIENTIST?

You'll be able to connect with all sorts of different people through Skype a Scientist. Below is one scientist out of over 2,000 who are willing and able to talk to you about their research.

NAME: Nora Mitchell

TITLE: Postdoctoral Fellow at The University of New Mexico

WHAT DO YOU DO?: I study hybridisation and evolution in Texas sunflowers! I want to show students around the world that there's no one way to be a scientist, and that #plantsarecooltoo!

NUMBER OF SKYPE SESSIONS: Seven

PAID TO STUDY, RESEARCH AND COMMUNICATE SCIENCE

UNDERGRADUATE SCIENTISTS AT THE **UNIVERSITY OF SAINT FRANCIS** IN THE US ARE RECEIVING SCHOLARSHIPS FROM THE **NATIONAL SCIENCE FOUNDATION** TO LEARN AND SHARE THEIR KNOWLEDGE WITH CHILDREN, TEENAGERS, THE PUBLIC AND INDUSTRY – AND IT'S ALL IN THE NAME OF BRITAIN'S FIRST SCIENTIST, ROGER BACON

WHO IS ROGER BACON?

- Roger Bacon lived from around 1214 to 1292 (his place and date of birth are unknown), and studied and taught at Oxford University in England
- He was an English philosopher and scientist – and was also believed to be a Franciscan Friar
- His research led to the development of glasses to improve eyesight
- He was imprisoned for having an interest in magic
- He believed that there is more to science than simply arguing about scientific concepts; science had to be experimented with and experienced. This idea forms the basis of the University of Saint Francis' Scholars programme.

**Source: BBC History*

At the University of Saint Francis (USF) in Indiana, USA, a group of undergraduate science students are benefiting from a unique programme that takes its inspiration from an early scientist – Roger Bacon. Students in the University's Roger Bacon Scholars programme are given opportunities to take the science they learn throughout their academic career and apply it to a wide range of activities, including: their own industry-inspired research projects, teaching in schools, presenting at conferences, and talking to companies about how their research can be used in the real world.

Initiated in 2014, USF has supported 16 Roger Bacon Scholars in the programme. Students hoping to study an undergraduate STEM subject (such as biology, chemistry, science and entrepreneurship, environmental science and mathematics) at the University can apply. Successful applicants not only receive scholarships from the National Science Foundation throughout their academic experience, they're also taught a life-long valuable skill: science communication.

WHAT HAPPENS IN THE SCHOLARS PROGRAMME?

The transition from school to university can be a challenge for any student. However, the students accepted in the Roger Bacon Scholars programme receive lots of additional support. They're mentored and tutored by professors and students at the university, and by people working in companies that are relevant to the subject of their research. They attend networking sessions and luncheons, run by USF's Career Services Office, that focus on developing the communication skills required to be successful in scientific internships and careers. The students also visit industry sites to create relationships with potential employers.

Unlike traditional undergraduate degree programmes, the students aren't just given information in a series of lectures that they're expected to learn; they have chances to apply the science they're taught both inside and outside the classroom to understand how it impacts the real world. In an environmental chemistry course, for example, Roger Bacon Scholar Tyler Lengerich worked with the Department of Health to collect

USF students worked with the Government's Department of Health to check for lead in wall paint chips.

MEET TWO ROGER BACON SCHOLARS

KAITELYN VACHON AND PETER MITCHELL TALK TO US ABOUT THE ROGER BACON SCHOLARS PROGRAMME AND HOW IT HAS BENEFITED THEM AND THE YOUNG PEOPLE THEY HAVE TAUGHT

paint chips from houses. He tested them in the lab to check whether there was any lead in these chips, which can be a health concern, and he did this for free.

IN WHAT WAY ARE THE STUDENTS MAKING A DIFFERENCE?

In their second year at USF, students work side-by-side with a research mentor to design a research project that seeks a solution to a scientific question, which is inspired by real-world needs. In their third year, the students complete the project and present their results at scientific conferences.

The four-year programme builds up to a capstone experience, which allows students to reflect on their academic, social and spiritual growth throughout their time at USF. As part of their Roger Bacon capstone expectations, the scholars create an outreach project for an elementary, middle or high school class. The aim of this outreach project is to teach an important aspect of their scientific research to schoolchildren.

This unique approach helps the scholars develop their communication skills, gain experience working with a broad range of individuals or groups, and foster critical thinking and creativity. What's more, these students are inspiring the next generation of scientists by sharing their enthusiasm for and knowledge in STEM subjects – skills that are helping Roger Bacon scholars maximise their employability.

Indeed, the Roger Bacon Scholars programme prepares graduates for a wide variety of career opportunities, enabling them to use their science degree to really make a difference in the world.

Kaitelyn taught a class of kindergarten children about the effects of pesticides on sea anemones.

KAITELYN VACHON

Kaitelyn has a BS in biology from USF with a minor in environmental sciences. She currently works for a local environmental waste management facility. When Kaitelyn was growing up, she was always fascinated by science, but it wasn't until she took part in biomedical, project-based learning classes in high school that her interest in biology was sparked.

MENTORS

Dr Andrea Geyer and Mr Warren Pryor

RESEARCH PROJECT

Studying the wider effects of pesticides on animals in the environment, beyond the insects that are pests

OUTREACH

Introducing sea anemones to kindergarten students to create an understanding of how they are affected by pollution

Read Kaitelyn's Q&A on the next page

WHAT IS CLOTHIANIDIN AND WHY ARE YOU RESEARCHING IT?

Clothianidin is a very effective chemical that kills insects that eat the plants that farmers are trying to grow. It causes the bugs to become paralysed and then die. Unfortunately, it's not only the unwanted insects that come into contact with such chemicals; there's increasing concern that they're affecting populations of bees, which are important for pollinating plants and producing honey.

HOW CAN STUDYING SEA ANEMONES HELP US UNDERSTAND WHAT'S HAPPENING TO BEES?

Sea anemones are easy to raise in the quantities we need for our research, and they aren't mobile. This means that their central nervous system, which controls how they move, is simpler to study. Their system is also more simplistic than that of bees, allowing us to study how pesticides influence movement a lot easier. Then, we can use this initial model – sea anemones – to begin to understand how the more complex, endangered bee species may be influenced by pesticides. While we're mainly trying to investigate the effects that pesticides are having on bee populations, the research is also meaningful for sea anemones because they can be influenced by pesticide exposure when chemicals are washed into the sea.

WHAT HAVE BEEN YOUR MAIN RESULTS SO FAR?

Our research has found that as levels of pesticide increase, the sea anemones move their tentacles more and more slowly until they become paralysed and cannot move them at all. If you watch the animals closely, you can see their bodies become still almost immediately after they are exposed to the pesticide.

I was hoping to be able to identify a 'safe' level of pesticide, but even using the tiniest amount of chemical (one drop diluted 3 billion times) still caused the sea anemones to display temporary paralysis. Further experiments will be needed to find the smallest amount of pesticide that causes paralysis.

THE ROGER BACON SCHOLARS PROGRAMME ENCOURAGES YOU TO PRESENT YOUR WORK AT CONFERENCES, COMMUNITY EVENTS AND IN SCHOOLS. HOW IMPORTANT IS THIS OUTREACH?

The outreach aspect of the research is the part that I get most excited about. There are hundreds of thousands of research projects going on around the world, but what's the point of all that effort if no one can understand the importance? We unfortunately live in a society where science is still considered 'scary' and, because of that, I wanted to make sure I was able to present my research in a friendly way on several platforms.

YOU INTRODUCED YOUR RESEARCH ON SEA ANEMONES TO KINDERGARTEN CHILDREN. WHAT DO YOU HOPE THEY GOT OUT OF THIS EXPERIENCE?

My goal with the children was for them to understand what sea anemones were and how they interact with the environment. I wanted to take concepts that they understood, such as recycling, and link it to pollution to give them a 'mascot' to cheer for in nature. Not only did we talk about sea anemones, but the kids also had the opportunity to feed them and see how the animals protect themselves.

> *"The kindergarten students enjoyed the sea anemone experience. The hands-on activities were age appropriate and the presenter was very well prepared. This was a wonderful opportunity for my young students to learn about something that would not normally be part of our curriculum."*
>
> Virginia Simpson, kindergarten teacher at Queen of Angels Catholic PreSchool

PETER MITCHELL

Peter Mitchell is a student in computer information systems at USF. As a child, he loved technology and would try to fix computers whenever he could. As this passion continued through high school, a degree in computer information systems seemed like an obvious choice. Once he graduates, Peter hopes to find a job that will make use of his experience in game design or audio networks.

MENTOR

Mr Rick Miller

RESEARCH PROJECT

Creative game design in DeKalb's Mutation Invasion

OUTREACH

Introducing the importance of planning in game development to 9th graders in DeKalb High School using their Mutation Invasion project. The project offers the students a chance to develop their own concept for a computer game and get a taste of what a career in computer science has to offer.

WHAT IS MUTATION INVASION?

Mutation Invasion is a project developed by DeKalb High School that involves designing a video or board game to save humanity and eradicate illness. The game must include a scientific discovery that helps find a cure, environmental factors that affect how the disease spreads, and a map showing where the disease has infected people. The project involves figuring out technical requirements, designing the game, building it using code, testing the game and further developing it based on the results of the tests.

WHAT DIFFICULTIES DID YOU FACE WHILE DESIGNING YOUR GAME?

My game development project was part of a final assignment in one of my programming classes. I worked on the project for most of a semester with two other students. Although we made a plan and a timeline, we had lots of big ideas that were unrealistic to put into practice with the time and resources we had. Because there was no clear leader of the group we often worked on the same parts of the project and we fell behind the plan. Although the game didn't end up being what we imagined and was missing lots of the features, I'm proud of the finished product. Not only that, I've learned a lot of important skills – team working, time management, managing expectations, and much, much more – all of which will help me in the future.

HOW DID YOU GET THE HIGH SCHOOL STUDENTS INVOLVED WITH YOUR PROJECT?

At the beginning of the Mutation Invasion project at Dekalb High School, I shared the lessons I learned from my programming class project. From there, the students began to make a game case to introduce the type of game they would make and the disease that would feature. They then made a game trailer to set the scene and a multimedia presentation to outline the main features of the game, such as geography/biology of the disease, the characters and the environment. They were also invited to play a portion of the game that I had created as part of my undergraduate project to further understand the content and goal. The students were asked to present their game idea to a panel of judges, which included myself.

HOW DID YOU BENEFIT FROM THE OUTREACH ASPECT OF YOURCOURSE?

Going into the high school classroom gave me the experience of presenting in a professional way in front of a large audience. It also gave me the opportunity to provide constructive criticism.

WHAT DO YOU HOPE THE HIGH SCHOOL STUDENTS GOT OUT OF THIS EXPERIENCE?

I hope that they were able to see the quality of the computer science programme at USF, and that I encouraged them to think about a career in computer science. I also hope that I helped them with their projects by providing quality feedback and sharing my experiences.

> *When Peter Mitchell spoke about his college experience in pursuit of career possibilities, the high school students also began to envision possibilities for their own future. When young people are exposed to aspiring career professionals that are not much older than them, it is empowering in a sense that encourages self-actualisation.*

Kelsey Pierce and Christina Lapham, teachers at DeKalb High School

CALLING ALL GIRLS AND YOUNG WOMEN: WISE UP TO A CAREER IN STEM*

WHETHER YOU'RE IMAGINATIVE, CONFIDENT, LOGICAL, CREATIVE, ORGANISED – OR SHY, EVEN – THERE ARE SO MANY WELL PAID AND REWARDING JOBS IN THE SCIENCES FOR YOUNG WOMEN. BUT GIRLS AND YOUNG WOMEN IN THE UK AREN'T CHOOSING CAREERS IN SCIENCE, TECHNOLOGY, ENGINEERING OR MATHS. WHY NOT? WE ASK **DR MHAIRI CRAWFORD**, DEVELOPMENT DIRECTOR AT WISE

* *SCIENCE, TECHNOLOGY, ENGINEERING AND MATHS*

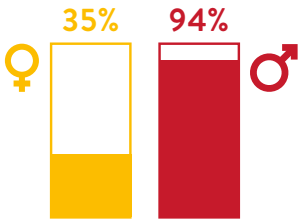
WHAT'S THE PROBLEM?

THERE ARE THREE MAIN AREAS OF CONCERN:

1. According to research by Social Market Foundation and EDF, 640,000 STEM jobs will need to be filled by 2023. That's in less than five years' time. But there aren't enough people studying STEM, meaning that employers won't be able to find the skilled employees they need, and the UK economy will suffer.

640,000
STEM JOBS NEED TO BE FILLED BY **2023**

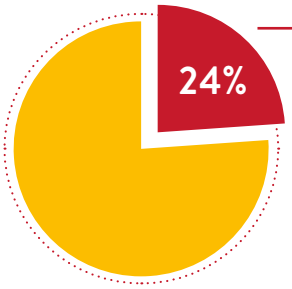
2. Even though girls tend to get better grades in science subjects at school (averaging 66% A-C at GCSE versus 62% A-C for boys), only 35% of girls choose to study maths, physics, computing or a technical vocations qualification after the age of 16. Whereas, 94% of boys go on to study these subjects. This means girls are avoiding subjects they are good at – and will probably be very happy doing – because they feel STEM is not for them.



Percentages of girls vs boys studying STEM subjects

3. In the UK, only 24% of people working in STEM industries – science, manufacturing, energy, computing, for example – are women. This means that women are missing out on jobs that make a difference to people's lives, are well paid and are incredibly important for the future.

And businesses aren't getting the skills they need, such as imagination, creativity, people skills and much, much more. Men have these skills, too, but without more women in STEM, there aren't enough people to fill the skills shortage.



Percentage of women working in STEM industries based in the UK

GE Aviation, Wales 2017 © WISE

WHAT'S THE SOLUTION? WISE UP TO A CAREER IN STEM

MHAIRI TALKS TO US ABOUT WISE, AND WHY IT'S IMPORTANT FOR GIRLS AND YOUNG WOMEN TO STOP SEEING STEM AS A CAREER CHOICE FOR MEN WHO WEAR HARD HATS OR SIT IN THEIR BEDROOMS WRITING COMPUTER PROGRAMS

ABOUT MHAIRI CRAWFORD

"I'm responsible for all the different offerings that WISE has, including People Like Me – which engages girls with careers in STEM (science, technology, engineering and maths) – and Ten Steps – which helps industry to make STEM more attractive to women. I'm also responsible for research and statistics analysis, and I get to think about what we need to do to change things in the future for girls and women."

ABOUT WISE

WISE stands for Women into Science and Engineering. It was set up in 1984 after a government committee, led by Sir Monty Finniston, found that there weren't enough skilled engineers in the UK.

www.wisecampaign.org

1) WHAT IS WISE AND WHAT DOES IT AIM TO DO?

Our goal is to support more women into STEM careers. We work from classroom to boardroom, and we do this by engaging young women to consider jobs in STEM, and by working with employers to help make the workplace a place where women are happy, successful and want to stay. Our immediate target is to have 1 million women working in core STEM careers (not medical STEM professions) by 2020. We're at over 850,000 at the moment, so we're on track!

2) WHY IS AN ORGANISATION LIKE WISE IMPORTANT?

WISE is unique. We work with employers to engage women, which means there's a real potential for change. As more companies become involved, the more incentives they'll introduce, i.e. something that encourages women to join their business – and this makes it easier for women to enter and stay in STEM careers.

3) WHY DO GIRLS AND YOUNG WOMEN AVOID STEM SUBJECTS AND CAREERS?

There are a number of reasons, but I think a lot of it comes down to perceptions. People often think of stereotypes of engineers wearing hard hats and high vis vests, or computer programmers sitting in their bedrooms in their underwear. These images don't help girls identify with roles like these – they probably don't see themselves like that – and they don't help parents or carers to identify these roles for their daughters. There's also the incorrect perception that girls aren't as good at STEM as boys, or that they shouldn't be doing hands-on, practical subjects. UK exam statistics show that this is wrong – girls are good at STEM – but it's taking years to address this.

4) WHY SHOULD GIRLS AND YOUNG WOMEN TAKE AN INTEREST IN SCIENCE, TECHNOLOGY, ENGINEERING AND MATHS?

Just think of the difference you could make. It's not just that there are so many roles out there that are fun, varied and interesting. Or that there are opportunities for travel or doing some really amazing things. You could make a huge difference to people's lives while doing something you enjoy. Not only that, over the 40-50 years you'll be working, a career in STEM pays around £250k more than a non-STEM career. Imagine what you could do with that.

RAF Leeming © WISE

WHAT'S THE SOLUTION? PEOPLE LIKE YOU

MHAIRI TALKS TO US ABOUT THE PEOPLE LIKE ME PROJECT, AND HOW IT'S HELPING GIRLS AND YOUNG WOMEN SEE THAT JOBS IN STEM ARE FOR PEOPLE LIKE THEM – AND YOU

1) WHAT IS PEOPLE LIKE ME?

Think how many years you're going to be working? Probably nearly 50 years. Wouldn't it be good to find something that will make you happy and successful? People Like Me uses research to help you find out which jobs in science, technology, engineering and maths might suit your personality type. It takes you through a quiz to identify your personality strengths, then matches you to a personality type in the workplace. You might be a manager, a policy maker, an entrepreneur or a supporter; once you understand where you could fit then you can explore careers that suit your strengths, helping you find a pathway to somewhere you could be happy and successful.

2) WHO'S IT FOR?

Anyone, but it was designed for 11-14-year-old girls to encourage them to choose STEM subjects at GCSE and post GCSE. Our new online People Like Me platform is aimed at the 11-18 age group – but, really, it works for any age group!

3) CAN BOYS AND YOUNG MEN USE PEOPLE LIKE ME, TOO?

Yes, but the research behind People Like Me highlighted that women and men (or girls and boys) tend to think slightly differently. Girls tend to use adjectives to self-identify, i.e. using words such as "artistic, friendly, intuitive" to understand the type of person they are. Boys like to use verbs to self-identify, i.e. using words such as "good at building, drawing, leading" to describe themselves. What this means is that while People Like Me works for boys and young men (and it does work), they may not feel comfortable using the adjectives in the quiz.

4) HOW DO YOU ACCESS IT?

The quiz is available online. You can print out the quiz and supporting materials from the WISE website: www.wisecampaign.org. On the website you'll find:

- The Personality Type quiz
- A glossary to help you with words you might not know
- A Job Analysis sheet to help you find jobs that suit your personality type
- Role models (see examples below)

ARE YOU LIKE THESE TWO ROLE MODELS?

IROSHAGUNATUNGA

Irosha is a practical person who works methodically to solve tricky construction and engineering problems. She relies on her patience and organisational skills in her job as a site engineer.

ANNABEL SUNNUCKS

Annabel is very friendly, outgoing and enjoys working with others. She's an efficient worker and a good problem-solver – all great skills to have in her job as an intern for CA Technologies.

FIVE REASONS – AND MORE – TO BECOME AN APPRENTICE

WHAT DO YOU KNOW ABOUT APPRENTICESHIPS? MORE IMPORTANTLY, HAVE YOU EVER CONSIDERED DOING ONE? AMAZING APPRENTICESHIPS, AN ORGANISATION THAT WORKS ON BEHALF OF THE UK GOVERNMENT'S NATIONAL APPRENTICESHIP SERVICE, SHOWS US JUST HOW AMAZING APPRENTICESHIPS ARE

WHY WAS AMAZING APPRENTICESHIPS SET UP?

Apprenticeships have evolved so quickly in the last few years, and now there is a huge range of incredible opportunities for young people to join some of the country's biggest, best-known and most exciting employers as apprentices.

But sometimes the sheer volume of information out there can make it hard for students to know where to start, for schools to know how to support them, and for employers to cut through the noise.

Getting the right information in front of the people who need it is what we do.

WHAT IS AMAZING APPRENTICESHIPS' RELATIONSHIP WITH THE UK GOVERNMENT'S NATIONAL APPRENTICESHIP SERVICE (NAS)?

Amazing Apprenticeships designs, develops and delivers a range of national projects that inform and inspire England's students about apprenticeships on behalf of the NAS, which is part of the Government's Department for Education. We work hand-in-hand with NAS.

WHAT EXACTLY IS THE ISSUE THAT AMAZING APPRENTICESHIPS IS HOPING TO ADDRESS?

Lots of students, teachers and parents just don't realise what today's apprenticeships are and where they can take you. There are some incredible programmes out there. Imagine leaving school and walking into a job at the BBC, Google, Rolls Royce, Amazon, Coca-Cola, or any one of the hundreds of innovative, fast-growing smaller companies out there. That's a real option for students – and that's why we need to share this information with young people.

OK, SO GIVE US FIVE REASONS WHY APPRENTICESHIPS ARE AMAZING.

There are so many things that make apprenticeships the perfect option for many school leavers. Here are my top five:

1) You earn while you learn, i.e. you're getting paid as soon as you leave school.

2) You get invaluable on-the-job experience, with mentoring from people who have a wealth of experience in your chosen industry.

ABOUT ANNA MORRISON

"As Founder and Director of Amazing Apprenticeships, I oversee all of our projects, working closely with the National Apprenticeship Service to look for exciting, engaging new ways to improve understanding and awareness around apprenticeships."

ABOUT AMAZING APPRENTICESHIPS

Set up in 2015, Amazing Apprenticeships helps students, teachers and employers to navigate the exciting, fast-changing world of apprenticeships. To do that, it delivers a range of inspiring projects designed to improve communication and understanding around apprenticeships between schools, students and employers.

www.amazingapprenticeships.com

> *"There are some incredible apprenticeship programmes out there. Imagine leaving school and walking into a job at the BBC, Google, Rolls Royce, Amazon, Coca-Cola, or any one of the hundreds of innovative, fast-growing smaller companies out there. That's a real option for students"*

3) You're immersed in the job every day, surrounded by opportunities to learn and progress. For example, your apprenticeship may lead to other training opportunities such as management training.

4) Apprenticeships are available in companies that people who are going to university full time dream of getting into one day. Here's a way of skipping the queue, saving tens of thousands of pounds in university fees and starting a dream job years before most people do.

5) Degree apprenticeships even offer the opportunity to gain a full university degree while you work, without any of the usual associated debt.

WOW, THAT DOES SOUND AMAZING. BUT DON'T YOU HAVE TO BE A CERTAIN TYPE OF PERSON TO GO ON AN APPRENTICESHIP?

Different levels of apprenticeship and different programmes have different entry requirements but, potentially, there are apprenticeships out there for everyone.

We talk to the country's leading employers every day, and they're crying out for driven, engaged applicants for apprenticeships of all levels – and from different backgrounds, too. They all have strong inclusivity policies, meaning that they actively encourage applicants from less well-represented groups in their workforce.

A great example is women in tech, engineering and other STEM fields. We hear from female students all the time who are worried about applying for jobs in these traditionally male-dominated fields – but every big STEM employer we work with is trying their hardest to encourage more applications from young women.

It's the same story for applicants from different ethnic or religious backgrounds, lower socio-economic groups, and from across the sexuality and gender spectrums. Top-flight employers want to hear from you, because they know how much you have to offer them. There's simply no such thing as a "typical apprenticeship applicant".

AMAZING APPRENTICESHIPS HAS WHAT IT CALLS "VACANCY SNAPSHOT" – A SNAPSHOT OF APPRENTICESHIP VACANCIES THAT ARE COMING UP SOON ACROSS ENGLAND. WHAT'S ITS PURPOSE AND HOW MANY VACANCIES ARE THERE, ROUGHLY?

Our Vacancy Snapshot platform has masses of information from leading STEM employers – including details of individual programmes, how and when to apply and much more – from the likes of Google, IBM, TFL, Siemens, Network Rail, RAF Engineering, Airbus and many more.

The official place to look for vacancies with all employers is on the government website 'Find an apprenticeship': https://www.gov.uk/apply-apprenticeship. On this site you'll find around 20,000 live vacancies at any one time.

Vacancy Snapshot is designed to work alongside this website and is a great first port of call for your apprenticeship journey. We've teamed up with a selection of the country's best-known apprenticeship employers to give you an overview of the opportunities they offer, looks behind the scenes, tips on maximising your application's chances, and much more.

WHAT OTHER RESOURCES DO YOU HAVE THAT ARE AIMED SPECIFICALLY AT YOUNG PEOPLE?

Our range of resources designed to help young people navigate the world of apprenticeships is huge – from printable resources like booklets, brochures, activity packs and posters to video and dedicated web platforms.

We have lots of live broadcasts available on catch-up with some of the country's biggest and best-known apprenticeship employers, featuring Q&As with real apprentices and information about what day-to-day life is like for apprentices at those companies. All of our resources are free. You can find them all at www.amazingapprenticeships.com

90%

OF APPRENTICES REMAIN IN EMPLOYMENT ONCE THEIR PROGRAMME IS COMPLETE.

FOR THE 10% THAT DON'T – THEY MIGHT DECIDE TO STUDY FULL-TIME AT UNIVERSITY OR SET UP THEIR OWN BUSINESS, GO TRAVELLING.

MEET AN APPRENTICE

APPRENTICES COME FROM ALL BACKGROUNDS AND CULTURES. AND MANY ARE MANAGING TO SIDE-STEP UNIVERSITY AND START EARNING A DECENT WAGE FROM ALL MANNER OF COMPANIES – GOOGLE, IBM, SIEMENS…. IF YOU'RE UNSURE WHETHER AN APPRENTICESHIP IS FOR YOU, WHY NOT TAP INTO THE YOUNG APPRENTICE AMBASSADOR NETWORK?

The Young Apprentice Ambassador Network is a community of apprentices and former apprentices who take the time to share their apprenticeship stories with young people, teachers, parents and employers. Anna Morrison tells us more.

HOW MANY YOUNG AMBASSADORS ARE THERE?

We currently have just over 600 Young Apprentice Ambassador Network members. These are all current or past apprentices who have volunteered to give their time to go into schools and colleges across England, and share their experience of being an apprentice.

HOW DO YOU GO ABOUT MEETING AND TALKING TO AN AMBASSADOR?

Inviting a Young Apprentice Ambassador to talk at a school is one of the best ways of helping them to share their story with the apprentices of tomorrow. Booking an Ambassador is easy – schools can book their talk by visiting www.amazingapprenticeships.com and clicking 'Young Apprentices Ambassadors'.

MEET SIMEON POWELL,

YOUNG APPRENTICE AMBASSADOR AND ACCOUNTS & REGISTRATION ADMINISTRATOR FOR MOTORPOINT

AGE: 26

APPRENTICESHIP: ASSOCIATION OF ACCOUNTING TECHNICIANS HIGHER APPRENTICESHIP, 2013

OTHER QUALIFICATIONS GAINED THROUGH THE APPRENTICESHIP:
TWO-YEAR MANAGEMENT PROGRAMME

WHY HE BECAME AN APPRENTICE:
"I wanted to work! Ultimately, I knew this would give me options in the future. In myself, I knew I wanted to start my career as early as possible, with the experience to earn more later. The fact I could be paid to do that is a bonus."

GROWING HUMAN LIVER CELLS "IN A DISH"

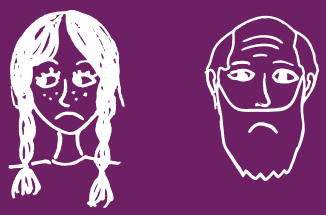
FULL LIVER TRANSPLANTS ARE THE MAIN TREATMENT OPTION FOR SEVERE LIVER DISEASE, BUT SUITABLE DONORS ARE IN SHORT SUPPLY. COULD STEM CELL TECHNOLOGY, IN WHICH HEALTHY LIVER CELLS ARE GROWN *IN THE LAB*, BE A SOLUTION TO THIS PROBLEM? **DR DAVE HAY** FROM THE **UNIVERSITY OF EDINBURGH'S CENTRE FOR REGENERATIVE MEDICINE** THINKS IT COULD

IMAGINE THIS SCENARIO

Alex is 12. He has a condition that is causing severe damage to his liver. To treat him, and get him back on his feet again, he needs a full liver transplant. However, there aren't enough healthy livers available, and he has been waiting for one for over three months. Alex is of Asian descent, which means there are fewer compatible donors available. How terrifying must that be? Imagine, though, if new, healthy liver tissue could be made in the lab. Scientists have discovered that this is indeed possible – with stem cell technology.

According to the UK's Foundation for Liver Research, 1 in 10 people will have a problem with their liver.

As of November 2018, 346 people are waiting for a liver transplant; 36 of which are under 18, according to the UK's National Health Service (NHS).



73 days 135 days

For adults, the average waiting time for a liver transplant in the UK is 135 days; for children this is 73 days (NHS).

A liver transplant involves removing a diseased liver and replacing it with a healthy one from a donor. While the operation may seem simple enough, it's not without risks or complications. Dr Dave Hay from the Centre for Regenerative Medicine at the University of Edinburgh has been using stem cells to make new, healthy liver cells. He hopes that these new cells could be made into healthy liver tissue to replace damaged tissue in patients – an exciting prospect that could offer an alternative to liver transplants.

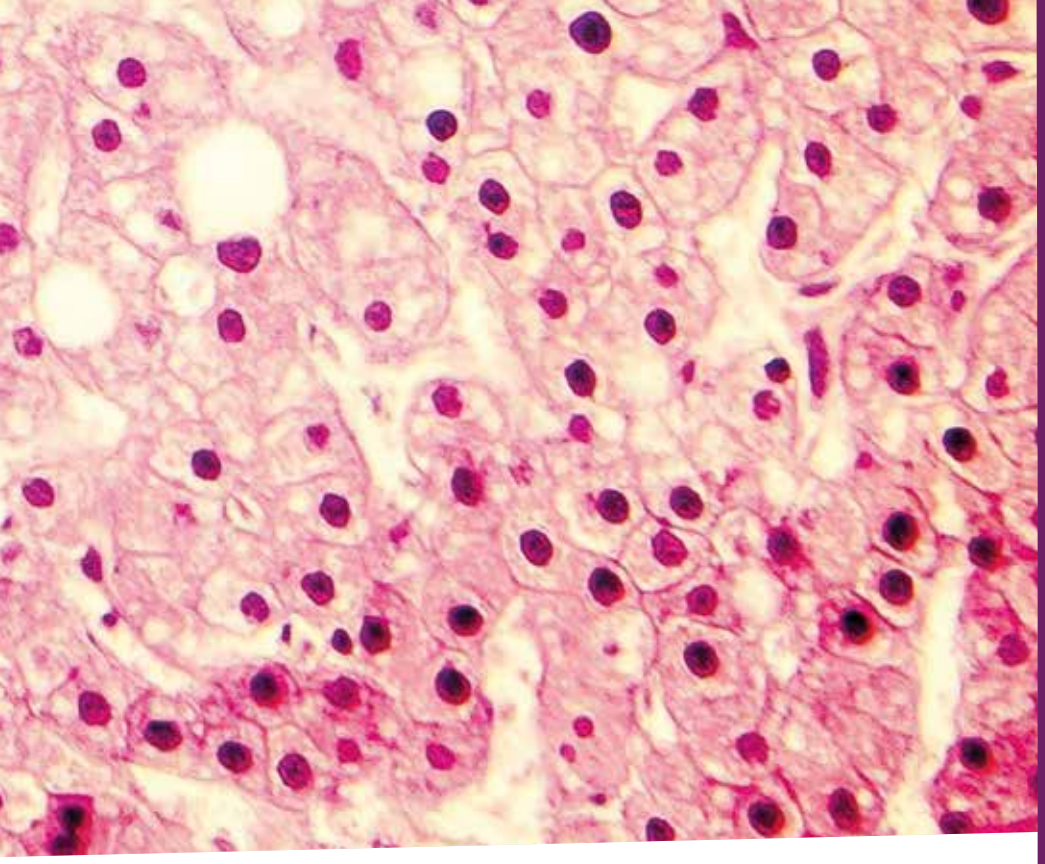
WHAT ARE STEM CELLS?

Stem cells are cells that are undifferentiated; that is, they don't yet have a specific job or function. Under certain conditions, they take on their functions and become specific cells such as bone cells, fat cells or muscle cells. Pluripotent stem cells are those that can be grown into any type of tissue in the body.

It's easy to see why, then, scientists have turned their attention to stem cell research. With stem cell technology, new cells of the needed type could be produced and used to replace damaged ones, and thus regenerate tissues and organs in patients.

WHAT DOES THE LIVER DO?

The liver is a large reddish-brown organ that sits to the right side of the belly. Its job is to filter the blood coming from the digestive tract and to break down and remove unwanted materials. It also produces bile – a substance that helps the small intestine break down and absorb fats, cholesterol and some vitamins. There are many other functions that the liver performs



such as assisting the formation of blood clots, aiding with mineral storage, and supporting the immune system to fight disease, to name a few.

As you can imagine, liver damage is bad news for the body. The damage reduces the liver's capacity to perform necessary functions. This negatively impacts a patient's health, and can result in death. It's vital, therefore, that liver disease is treated and that this is accompanied by the necessary lifestyle changes such as giving up or reducing alcohol intake, eating a balanced diet and exercising regularly.

HOW IS SEVERE LIVER DISEASE NORMALLY TREATED?

Some medications and surgical procedures may help. However, in cases of severe damage, a full liver transplant is the only option. The problem is, livers are in short supply. In some areas, suitable donors are unavailable. The shortfall of suitable donors can also be worse for some patients depending on their ethnicity and the country in which they reside. Using stem cells to grow liver tissue in the lab, therefore, is seen as a possible solution to this problem.

HOW DO YOU MAKE NEW LIVER CELLS?

Making new cells in the lab is a complicated process. "In a nutshell," Dave explains, "making new cells in the lab involves feeding the stem cells different factors and nutrients that are involved in human development".

Depending on the conditions the stem cells are exposed to, scientists can make different types of cells, such as hepatocytes, the main cell type of the liver. "Our interest is in the liver and, in particular, producing hepatocyte-like cells," says Dave. "Our cells are similar to human adult liver cells but possess major foetal and neonatal attributes. So, we call them hepatocyte-like cells, and not hepatocytes, because they're not fully mature."

In the lab, Dave and his team use a material known as "agarose" in which liver spheres form. Agarose is a material that is extracted from seaweed and used to make gels. These gels, when set, are the perfect growth medium. "Cells don't bind to the agarose, meaning that they attach to each other and self-assemble into clumps," says Dave. And it's these clumps of new, healthy tissue that could be implanted into a patient in the future.

HOW LONG WILL IT BE BEFORE LAB-GROWN LIVERS ARE USED TO TREAT PATIENTS?

Research by Dave and his team has found that their specially-designed liver tissue implants supported liver function in mice with a certain type of liver disease – an advance that could be the first step towards developing liver tissue implants for people.

For now, the researchers are focusing on being able to transplant small fragments of liver tissue into a patient until a suitable donor organ becomes available for transplant (rather than growing a full human liver). And the team are in the process of working with industry and writing grants to move towards this. Reflecting on current progress, Dave commented, "What I can say is this – we have a stable and renewable product we can apply to study human liver biology in the lab and hopefully one day use in the clinic."

But, before any new therapy or intervention can be used on people, scientists have to show that that their work could become a reality – a process known as proof of concept – and conduct clinical trials. Dave hopes to have this proof of concept within the next five years.

DR DAVE HAY

Professor of Tissue Engineering
Centre for Regenerative Medicine
University of Edinburgh, UK

FIELD OF RESEARCH

Regenerative Medicine, Tissue Engineering and Stem Cell Biology

RESEARCH PROJECT

Dave's research focuses on using stem cells to engineer tissue types and organs in the lab. For example, he has been working with pluripotent stem cells to create liver cells and tissue, with the goal of developing alternative treatment options to full liver transplants.

FUNDERS

UK Regenerative Medicine Platform; Chief Scientist Office of Scotland

ABOUT TISSUE ENGINEERING

Tissue engineering is an exciting field of study and many scientists and medical professionals feel it has great potential to treat numerous diseases. We ask Dave to tell us more about it.

WHAT IS TISSUE ENGINEERING AND HOW DOES IT FIT WITHIN THE WIDER CONTEXT OF STEM CELL RESEARCH AND REGENERATIVE MEDICINE?

Tissue engineering is the field of research that combines cells with biologic and synthetic components to build functional units of tissue. This allows the researcher to study tissue assembly, function, health and disease "in the dish". It may also be later deployed within a clinical setting to treat loss of function or disease.

IS REGENERATIVE MEDICINE BEING USED IN HOSPITALS NOW?

Yes, bone marrow transplant is a good example of stem cell therapy. With regard to pluripotent stem cell-derived therapies, they have been used clinically to successfully correct macular degeneration [a cause of sight loss] and will be used this year in trials aimed at treating Parkinson's disease.

IF RESEARCH SUCH AS YOURS WON'T BE IN EVERYDAY USE FOR SO MANY YEARS, WHY GET EXCITED ABOUT IT?

Our ability to make human tissue from any individual – subject to consent and ethics processes – enables us to study their characteristics "in a dish". This allows us to better understand disease and tailor make treatments for that disease. That's exciting because the technology will provide us with great opportunities to treat tissue damage and degenerative diseases. These technologies will transform medicine as we move through the next 10-20 years.

OTHER THAN GOING TO UNIVERSITY, ARE THERE OTHER ROUTES TO WORKING IN STEM CELL RESEARCH OR REGENERATIVE MEDICINE?

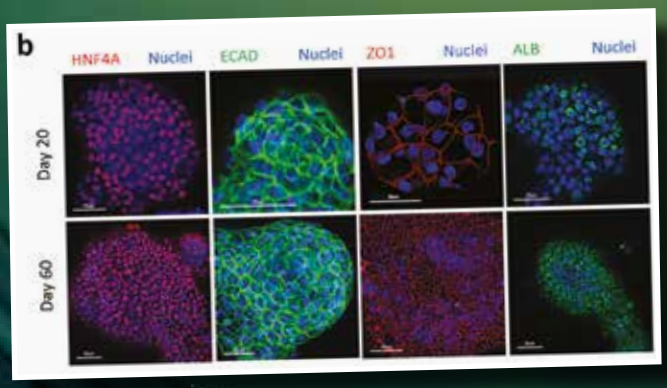
Yes, regenerative medicine is a broad field, spanning many disciplines. Therefore, a number of routes are available. For example, you could work in administration, technical assistance, quality control, facilities maintenance and project management. This could be within an established company or a start-up company.

WOULD YOU RECOMMEND REGENERATIVE MEDICINE AS A REWARDING CAREER OPTION FOR YOUNG PEOPLE?

I really enjoy my job. It has its challenges, but these are outweighed by its rewards!

OPPORTUNITIES IN BIOMEDICAL ENGINEERING

- Tissue engineering is a highly specialised field of research, so it will require a bachelor's degree in biology or related field, and then postgraduate qualifications in biomedical engineering. Check with your local university to see what options are available to you
- Another option, if you would like to see if working in biomedicine or a clinical setting is for you, is to do a course in medical laboratory technology. Technical training centres offer suchlike courses
- In the UK, biomedical engineers earn between £21,000 and £45,000



Evaluation of hepatic markers at gene and protein level

ASK DR DAVE HAY

WHAT DID YOU WANT TO BE WHEN YOU WERE YOUNGER?

Initially, a footballer. The problem was, I wasn't very good at it! But I always enjoyed biology and chemistry at school, and this led me to study biochemistry at university.

ACCORDING TO WILLIS TOWERS WATSON, MORE THAN 60% OF CHILDREN ATTENDING SCHOOL TODAY WILL WORK IN A CAREER THAT DOES NOT CURRENTLY EXIST. WOULD YOU SAY YOU'VE HAD A SIMILAR EXPERIENCE, I.E WORKING IN A REVOLUTIONARY FIELD THAT MAY NOT HAVE BEEN PARTICULARLY MAINSTREAM WHEN YOU WERE GROWING UP?

The isolation and reprogramming of human pluripotent stem cells had not been achieved until 1998 and 2007, respectively, so human pluripotent stem cell research was not mainstream until I was in my late 20s. So, yes, I definitely experienced that.

WHAT DO YOU LOVE MOST ABOUT YOUR WORK?

My job is great as it's never the same each day. It includes supervising students, giving international presentations, examining experimental results, writing papers and grants, setting up companies.... There's always something to be done! In science and grant writing there's an element of trial and error, and taking criticism. The secret is not to become down about what people perceive as failure; rather to use any feedback you receive to reshape your thoughts and deliver success in the future.

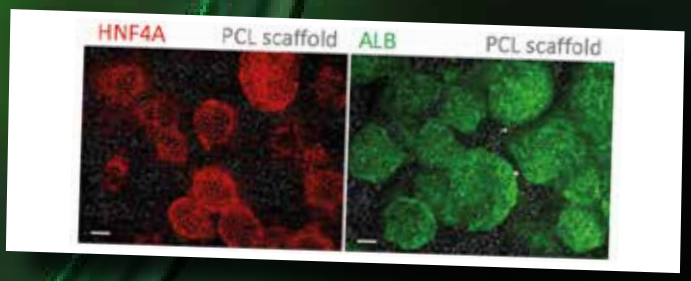
HOW WOULD YOU DESCRIBE YOURSELF? ARE THESE CHARACTERISTICS/PERSONALITY TRAITS USEFUL IN A CAREER LIKE YOURS?

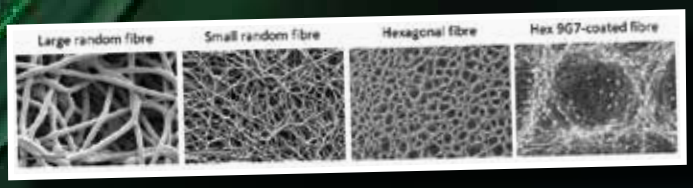
I'm hard working and determined. I think these are very important for a scientific career, as well as others. But it's not all work; I enjoy spending time with my family, going on holiday to warm places, working out in the gym, good food and going out! Balance is also very important.

WHAT ADVICE WOULD YOU GIVE TO YOUNG PEOPLE WHO ARE STARTING OUT ON THEIR CAREER PATH, BUT AREN'T SURE ABOUT WHAT THEY'D LIKE TO DO IN THE FUTURE?

My advice would be to follow what interests you most. In this way you'll not feel like you're just working to an end. Rather, you'll feel like you're following your curiosity. This will make you more motivated.

> *"I wanted to be a footballer when I was younger. The problem was, I wasn't very good at it! But I always enjoyed biology and chemistry at school, and this led me to study biochemistry at university."*





Development and characterisation of sub-cutaneous implants

FINDING JOY IN AN APP

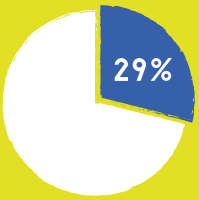
FOCUSING ON THE POSITIVES AND JOYFUL MOMENTS IN OUR LIVES CAN HELP US TO BUILD RESILIENCE, COPE WITH CHALLENGES AND BE THE BEST WE CAN BE. BUT CAN AN APP HELP US TO DO THAT? RESEARCHERS AT **MCMASTER UNIVERSITY** THINK IT CAN

IMAGINE THIS SCENARIO

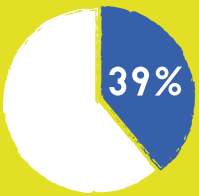
It's the end of the school year and exams are approaching. Adisa and Mary want to do well, but they're finding it increasingly hard to find time to study: there's the sports club, friends to hang out with and school work to do. Not only that, Adisa's parents are starting to give him a hard time, and Mary has fallen out with their friendship group. Adisa feels he should be there for her, but it's all getting a bit much. There doesn't seem to be anyone for Adisa or Mary to talk to.

According to the Ontario Student Drug Use and Mental Health Survey (OSDUHS):

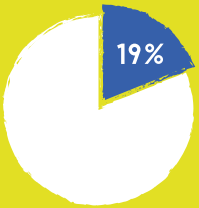
Over one-quarter (29%) of students believe that their mental health affects their school grades a "great deal" or "quite a lot.



Over one-third (39%) of students report that they rarely or never talk to their parents about their problems or feelings.



Almost one-in-five (19%) rate their mental health as fair or poor.



Life is a journey full of challenges, triumphs and all that's in-between. When we're faced with challenges, this can leave us feeling tired, stressed and worn out emotionally. And it can be hard to stay positive and keep our negative emotions in check. We might think about getting more sleep, exercising or setting up a study routine, but what about self-compassion and being kind to yourself?

According to research conducted by Dr Christine Wekerle and her team in Ontario, Canada, youth who have experienced adverse childhood events such as abuse are less likely to display problem behaviour if they have high levels of self-compassion. It appears, then, having a resilient mindset allows us to keep mentally and physically well, but keeping positive is easier said than done. With this in mind, Chris and her team have designed an app known as "JoyPop" that can help young people build on their resilience on a daily basis.

WHAT IS RESILIENCE?

According to the American Psychological Association, resilience is "the process of adapting well in the face of adversity, trauma, tragedy, threats or significant sources of stress — such as family and relationship problems, serious health problems or workplace and financial stressors".

Chris has devoted much time to studying resilience and how youth can build it. From her studies, she has found that most young people have incredible resilience potential. However, she has also found that youth find it difficult to manage their emotions, organise their thoughts, and express themselves – making it harder to unlock this resilience potential.

"There are different ways to think about stress,"she says. "'Positive stress' is the kind of feeling that can push you towards completing a task even though you're a bit hesitant. 'Tolerable stress' is when you know you can do whatever it is you need to do, but you feel stressed about doing it. 'Toxic stress' is the overwhelming feeling that you're not able to cope. One or two traumatic experiences might lead to toxic stress, as well as traumatic circumstances that have occurred throughout your childhood, such as living with family members who have problems with alcohol, drugs or violence."

HOW CAN WE BE RESILIENT?

We all have a natural resilience, but how we tap into this will depend on how much attention we pay to it. In any given day, resilience can fluctuate, meaning that the same difficulty or challenge will feel harder to overcome at different times in our lives. Many people believe that the key to experiencing joy is by eliminating negativity altogether. But, in a lot of cases, we cannot run away from the challenge; nor change the circumstances we're in. Chris suggests that we should, instead, focus on the positives. Positive thinking, and the feeling of joy that goes with it, can help us to routinely draw on our resilience.

Find this article online and download the activity sheet: https://futurumcareers.com/dr-christine-wekerle-finding-joy-in-an-app

DR CHRISTINE WEKERLE

Associate Professor of Paediatrics
Offord Centre for Child Studies
McMaster University, Canada

FIELD OF RESEARCH

Paediatrics, Clinical Psychology, Adolescent Health, Violence Prevention, Resilience

RESEARCH PROJECT

JoyPop is an app that helps you to track changes in your mood, focus your attention, organise thoughts, and engage in positive activities. In turn, this helps you to manage stress, deal with challenging circumstances and make good decisions.

FUNDER

Canadian Institutes of Health Research Grant No. 138302

HOW DOES JOYPOP WORK?

JoyPop is a product of Chris's research into resilience, and she has worked with young people to create it. The app has been designed to help users become better aware of their emotions, track the changes in their mood, focus their attention, organise thoughts and engage in positive activities. It achieves these goals by way of the following features, which are immediately available on the landing page:

- EMOTION RATINGS: The app asks you to rate your happiness. If it's below 50%, it will help you identify the negative emotion you're experiencing, and follows this up with some suggested activities
- ACTIVITIES: The activities help you to re-focus, de-stress and stimulate learning
- BREATHING EXERCISES: There are two breathing exercises to help you feel balanced and relaxed
- JOURNAL ENTRIES: This journal feature allows you to express yourself by putting your thoughts and emotions into words. The app gives you prompts to get you started
- CIRCLE OF TRUST: The so-called "Circle of Trust" enables you to enter up to six contacts (friends, family members, teachers, etc.) – people you can call when you need support. There's also a helpline, which is just an icon touch away
- CALENDAR: All of the above activities can be saved into your calendar, so you can discover what works best for you.

"Checking in on your emotions – when this is paired with a menu of activities to boost positivity – is like taking your temperature and being empowered to act in response," says Chris. "You can plan what to do next to boost your 'pops' of joy. The great thing is you have lots of options."

WHO EXACTLY WORKED ON THE APP, AND WHY?

Chris and her team felt that an app would be a great tool for helping young people to draw on their own resilience – but nothing like this currently exists. To understand what would appeal to the youth, she worked with undergraduates at McMaster University, in Canada, professionals who work with young people, and a group of youth advocates, aged 16 and up, who ran a weekly Twitter account called TEARtalk (Teens Ending Abusive Relationships). Clearbridge Mobile, an app development company based in Ontario, helped create the app in full.

WHO IS JOYPOP AIMED AT AND IS IT AVAILABLE NOW?

Anyone can use JoyPop. At the moment, it's being tested among youth who are in their first year at university, which for many is a stressful time. But the app's features have been designed to appeal to boys and girls as well as young men and women.

The app is still in this testing phase, with Chris and her team working on further research studies to understand how the app might be adapted to different circumstances; for example, for youth living in adverse environments. The aim, though, is to have it available in 2019 for anyone who feels they could do with a little more positivity in their lives.

Using the JoyPop app to keep positive

ABOUT CLINICAL PSYCHOLOGY

Clinical psychology is a branch of science that focuses on the study of the mind. It integrates many other types of study such as developmental science, neuroscience, population health, and mechanisms of change (understanding how and why people change their behaviour). In a practical sense, clinical psychologists use psychological science theory, laboratory studies and human research to identify models of distress or dysfunction, as well as wellness, resilience and personal development. Clinical and resilience interventions can then be developed and tested for effectiveness and impact.

WHY DO WE NEED CLINICAL PSYCHOLOGISTS?

Clinical psychologists help people to deal with trauma, mental illness and behavioural problems. There are so many different contexts where clinical psychologists are valuable – workplace wellness, mental health, first aid, humanitarian crises, coping with climate disasters, family dynamics and dysfunction, school bullying, cyberbullying, sexual exploitation, social justice, advocacy, policy and good government, and so forth. Clinical psychology may also be a stepping stone to many other areas such as the military, public health and international rights. Given that clinical psychology has such broad applications and can help people with such a large variety of problems, clinical psychologists are well sought after.

WHAT PASSIONS AND PERSONAL QUALITIES DO YOU NEED TO WORK IN THIS FIELD?

A curious mind is critical. On a personal level, compassion is an important quality to have. That's why getting involved with community-based, collaborative activities is a good idea if you want to pursue a career in psychology. Psychologists will encourage you to spend time with those who are experiencing psychological or psychiatric challenges, because it's important to confirm that you have the needed compassion and are able to work in these sensitive areas. It's also a great way to learn how to deal with the unexpected. In summary, excellent communication and interpersonal skills are needed.

HOW DO YOU BECOME A PSYCHOLOGIST?

Of course, the process of becoming a clinical psychologist will differ from country to country. This is especially true when it comes to registering as a practitioner after your studies. Generally speaking, however, it begins with an undergraduate degree in psychology at university, which teaches the fundamentals of psychology. After that, you'll need to undertake postgraduate studies in clinical psychology – usually either a postgraduate diploma or a master's degree. Then, you'll need to earn a doctorate.

OPPORTUNITIES IN CLINICAL PSYCHOLOGY

- Your local university will almost always offer a bachelor's course in psychology, even if it works with another institution to provide it
- One of the best ways to get involved, and see if psychology is for you, is to volunteer at a local organisation. Doing so is even more important during your university studies
- The Psychology Foundation of Canada is always on the lookout for volunteers interested in psychology, mental health, education, non-profit work or event planning
- While it does vary, a clinical psychologist can expect to earn from about US $50,000

Find this article online and download the activity sheet: https://futurumcareers.com/dr-christine-wekerle-finding-joy-in-an-app

ASK DR CHRISTINE WEKERLE

WHAT DID YOU WANT TO BE WHEN YOU WERE YOUNGER?

A ballet dancer, theatre actor, painter.... My mother, though, was insistent that I become a doctor of some sort. I did really like science, especially chemistry.

When I was a child and a teenager, I pushed myself a lot. I submitted poetry to a library contest; I sent my clothing and shoe designs to a department store contest; I got myself an agent for acting. Looking back, all of these learning experiences helped me deal with the unexpected, and tested my skills and boundaries. They helped me to focus on what I really wanted to do so I could let go of things I wasn't so good at or prepared to do.

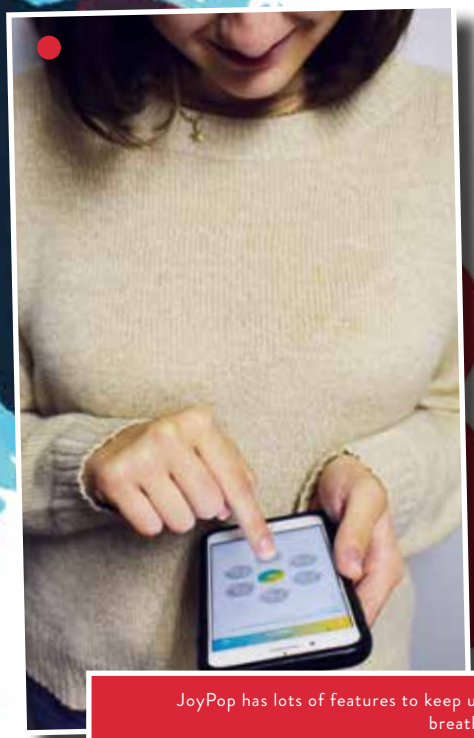
WHICH SUBJECTS DID YOU END UP STUDYING AT UNIVERSITY?

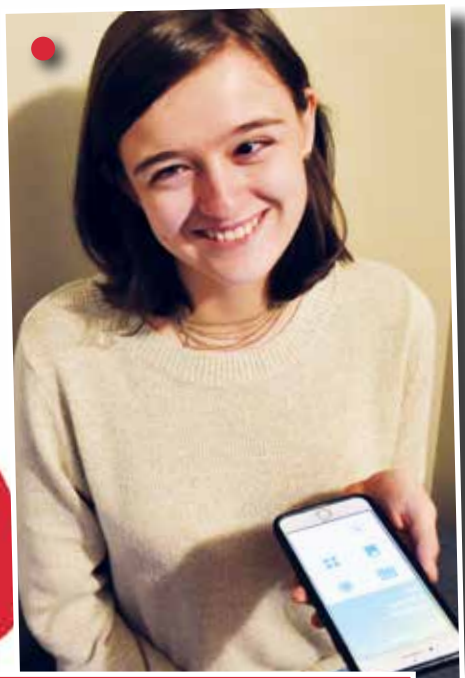
I did an honours undergraduate degree in psychology, before going on to graduate school where I studied clinical psychology.

IF YOU COULD GO BACK IN TIME WHAT ADVICE WOULD YOU GIVE YOURSELF WHEN YOU WERE STARTING OUT ON YOUR CAREER PATH?

Stick to your undergraduate resilience programming – in other words, dance classes, sport, theatre, whatever you enjoy doing. Self-care is too easy to push to one side when things get really busy, but it helps with everything else you're doing because you're managing stress. There's lots of evidence to show that exercise is good for mild to moderate depression and anxiety.

> *"Given that clinical psychology has such broad applications and can help people with such a large variety of problems, clinical psychologists are well sought after."*





JoyPop has lots of features to keep users feeling positive, from emotion ratings to breathing exercises.

CATHERINE ODENDAAL

MBChB Graduate Entry Medicine (4-year)

University of Birmingham, UK

CURRICULUM VITAE

12 GCSEs Grade C and above (Maths A; Double Science A A)

A Level: Biology A; Maths B; Chemistry B

AS Level: Art B

WILL THIS BE THE DOCTOR THAT SAVES YOUR LIFE?

CATHERINE ALWAYS WANTED TO BE A DOCTOR FROM A VERY YOUNG AGE, BUT SHE DIDN'T QUITE MAKE THE GRADES AT FIRST. NOW IN HER THIRD YEAR OF MEDICINE AT THE UNIVERSITY OF BIRMINGHAM, WE ASK HER HOW SHE DID IT

"I OCCASIONALLY GET SCARED AT THE THOUGHT OF THE INCREASING RESPONSIBILITY I'LL HAVE OVER PEOPLE'S WELLBEING. BUT I TRUST IN MY TRAINING THAT I'LL BE READY FOR THIS WHEN THE TIME COMES."

WHAT WAS IT THAT INSPIRED YOU TO BECOME A DOCTOR?

At a young age I was fascinated by medical documentaries; I always thought that medicine looked like such an exciting profession. When I was able to get some work experience in a hospital at the age of 17, I was invited to attend theatre on my second day! That was a defining moment and I knew medicine was the right career for me.

YOU DIDN'T QUITE GET THE GRADES YOU NEEDED TO STUDY MEDICINE AT FIRST. HOW DID YOU GET AROUND THAT?

I did a biomedical science degree first and, once I'd graduated, I was able to study medicine.

WHY DID YOU CHOOSE TO STUDY AT THE UNIVERSITY OF BIRMINGHAM?

I first considered Birmingham because I was familiar with the city. It was also close enough to family to avoid long journeys if I wanted to visit home. When I was offered an interview – and visited the campus and medical school for the first time – I immediately fell in love with the idea of being here.

DO YOU HAVE TO BE A CERTAIN TYPE OF PERSON TO STUDY MEDICINE?

Yes and no. There are certain qualities that are essential to be successful in the medical profession, such as honesty, empathy, problem solving skills, the ability to work in a team..., the list goes on. However, no student studying medicine is the same. If I look at my class of colleagues there's such a huge variety of personalities, interests, strengths and weaknesses. Yet all of them fulfil the criteria of making a good doctor in a different way.

WHAT DO YOU LIKE ABOUT THE COURSE?

Now that I've moved onto the clinical portion of my degree, I really like the fact that all of my time is spent in clinical settings, whether in a hospital ward, a clinic or in general practice. No day is the same.

AND WHAT DON'T YOU LIKE?

On the flip side, being a medical student in a large hospital with a lot going on can sometimes make you feel like a fish out of water, and some days just aren't what you want them to be. Staff may be too busy to teach you, or you're just unlucky in being

able to find the learning opportunities you were hoping for. You just have to take it as it comes and learn to rely on yourself as an independent learner.

THE UNIVERSITY OF BIRMINGHAM IS LINKED TO QUEEN ELIZABETH HOSPITAL BIRMINGHAM. HOW MUCH OF YOUR TIME IS SPENT THERE?

So far, I've spent one semester at the Queen Elizabeth Hospital. I've also had placements in Hereford, Dudley and Worcester. There are a lot of teaching hospitals and GP practices in Birmingham and surrounding areas, which are linked to the medical school I'm at.

HAVE YOU HAD AN EXPERIENCE AT A HOSPITAL OR OTHER CLINICAL SETTING THAT EITHER LED YOU TO QUESTION YOUR CAREER CHOICE OR MOTIVATED YOU TO CONTINUE?

I've witnessed some very challenging things, which haven't made me question my choice in career but have brought home the realisation of what I'm undertaking and how difficult it can be at times. I occasionally get scared at the thought of the increasing responsibility I'll have over people's wellbeing, but I trust in my training that I'll be ready for this when the time comes. There are lots of things that motivate me, even if it's a small compliment from a senior doctor or putting the training into practice and doing it well – it makes you believe that you're capable of doing the job!

WHAT WILL HAPPEN WHEN YOU FINISH THE COURSE?

When I graduate, I hope to enter the two-year foundation programme as a junior doctor. After that, I have a lot of options open to me and I can think about specialising in a specific area.

OTHER THAN BECOMING A DOCTOR, WHAT OTHER AVENUES ARE OPEN TO STUDENTS ON YOUR COURSE?

When undertaking a medical degree there's an option to intercalate in a different subject ['to intercalate' means to take another degree as well as the medical degree]. Depending on the subject you choose, this will open up several other opportunities. For example, if you chose to study business management, this would put you in good stead for a medical management position in the future. There are some pretty niche jobs out there that require a medical degree. Or at least, your medical degree would be a distinct advantage if you decided not to become a doctor: coroner, researcher, medical journalist, clinical lecturer; there's also the medico-legal stuff. I know a lot of people do intercalating degrees if they're specifically interested in different areas like law or business.

A student practises giving an intramuscular injection

Interpreting patient observation data

A student practises cardiopulmonary resuscitation (CPR) on a simulated patient

THE ATOMIC NUCLEUS: GREATER THAN THE SUM OF ITS PARTS

DR JACEK DOBACZEWSKI IS LOOKING AT WAYS TO SIMPLIFY A COMPLEX PHYSICS PROBLEM: HOW TO BETTER DESCRIBE THE ATOMIC NUCLEUS – AND IT'S A QUESTION HE'S WILLING TO SPEND A LIFETIME ANSWERING

IMAGINE THIS

In 1909, Ernest Rutherford conducted what has since become a famous experiment. At that time, everybody believed that atoms had the same consistency throughout their structure, with negatively charged electrons scattered about inside. Ernest was irradiating a thin foil of gold with alpha radiation and, as expected, the vast majority of particles went straight through the foil.

However, every now and then, some alpha particles bounced back, as if they had hit something solid. It's difficult to overstate how surprising this was at that time; it was like shooting a bullet at a piece of paper and have it rebound back towards you. After tracing many particles and examining the patterns, Ernest realised that matter must be composed of very small objects in the centre of atoms – something now known as the atomic nucleus.

Since Ernest Rutherford discovered the atomic nucleus more than a century ago, researchers have found that it is a composite object built of both protons and neutrons. Every chemical element has a different composition, each with a different number of protons, and new ones are still being discovered. Indeed, just a few years ago, the heaviest chemical element known to humankind was discovered and its name – Oganesson-294 – was coined in 2016. It was taken from the family name of a Russian nuclear physicist of Armenian origin, Youri Oganessian.

Oganesson-294 is built out of 294 constituent particles; its nucleus contains 118 protons and 176 neutrons. Unfortunately, it's impossible to describe the properties of Oganesson-294 by considering all possible interactions between its protons and neutrons, so Dr Jacek Dobaczewski, based at the University of York, is trying to simplify the problem. Jacek and his team try to devise theories that will describe composite systems as a whole and discover whether there are general rules that govern their structure.

WHAT DOES JACEK HYPOTHESISE IN HIS CURRENT RESEARCH PROJECT?

If we think of the 294 constituent particles of Oganesson-294 and then imagine a village of 294 inhabitants, with 118 men and 176 women, we can get a sense of Jacek's research. To describe the social mechanisms of the village, we might move away from detailed interactions between inhabitants and instead focus on some aggregate features. For instance, how many families live next to the village pond? How many along the river? How many close to the highlands? To gain an understanding of the village, it's probably less relevant to concentrate on where any given individual lives, and more relevant to consider where fishermen or shepherds live.

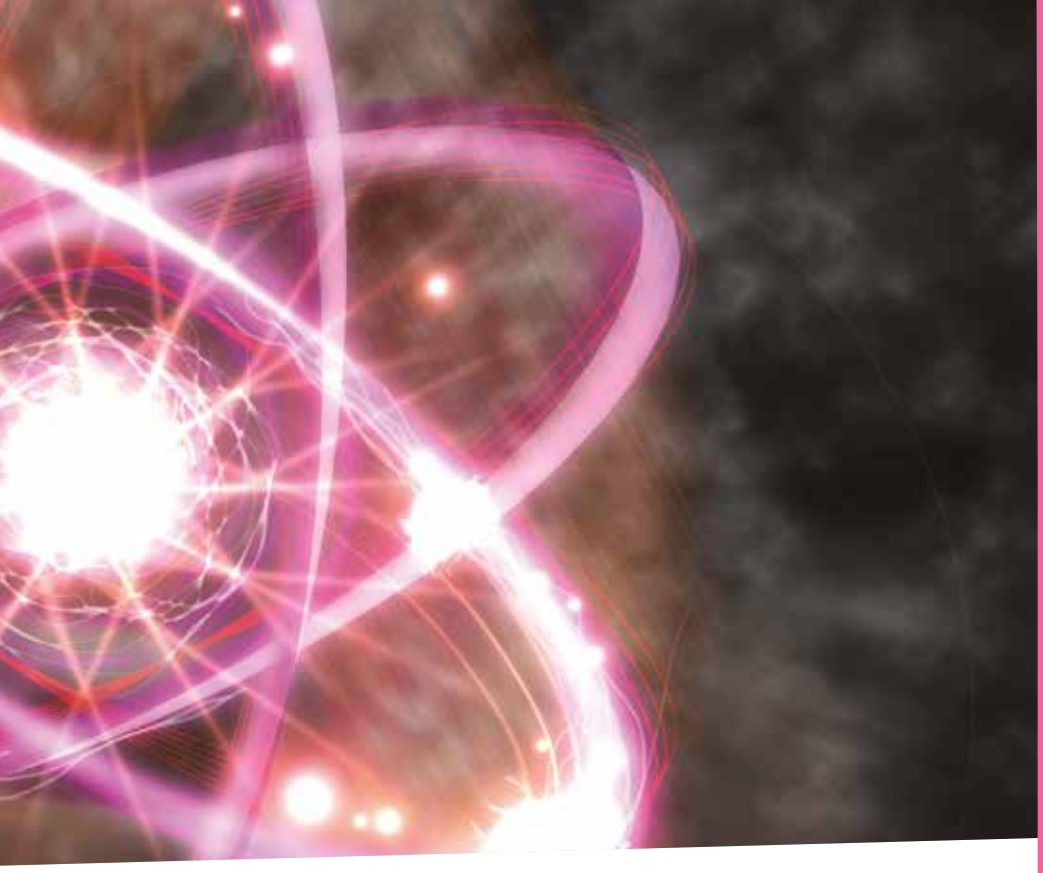
The principal hypothesis of Jacek's research is that the atomic nucleus can be better described by aggregate quantities, like the densities of protons and neutrons, and not by the positions and interactions of individual particles.

WHAT ARE THE POTENTIAL APPLICATIONS FOR NUCLEAR PHYSICS?

Nuclear physics has often been associated with dangerous ideas and catastrophic results. Nuclear weapons are a continuous cause for concern, as is nuclear waste and nuclear accidents such as the Chernobyl disaster that occurred in 1986.

However, nuclear physics also makes enormous positive contributions to society, such as nuclear energy which heats homes, nuclear radiation that helps cure cancers, and nuclear magnetic resonance that enables doctors to look inside our bodies. "Over the past few decades, nuclear physics has had a great impact on technology and society," says Jacek. "This will undoubtedly continue in the future, with thousands of nuclear scientists working on a variety of technological applications for nuclear physics."

Find the article online and download the activity sheet: https://futurumcareers.com/the-atomic-nucleus-greater-than-the-sum-of-its-parts



DR JACEK DOBACZEWSKI

Chair in Theoretical Nuclear Physics
University of York, UK

FIELD OF RESEARCH

Theoretical Nuclear Physics

RESEARCH PROJECT

Jacek's work aims to simplify the problem of describing the atomic nucleus of chemical elements. His research will devise theories that will describe the composite system as a whole, mainly through attempting to discover whether there are general rules that govern its structure.

FUNDER

Science & Technology Facilities Council (STFC) Grants No. ST/M006433/1 and No. ST/P003885/1

Not every investigation and research project have to have a definitive practical aim – many researchers work in the field of nuclear physics out of curiosity. Jacek can be said to fall into this camp, as he works to understand how composite quantum objects are built from their simple constituent parts.

HAVE ANY IMPORTANT DISCOVERIES BEEN MADE IN THE FIELD OF NUCLEAR PHYSICS IN THE LAST FEW YEARS?

Many of the heaviest chemical elements have been discovered in recent times. Oganesson with an atomic number of 118 was synthesised in 2002, Tennessine with an atomic number of 117 in 2010, and Livermorium with atomic number 116 in 2006. These syntheses were extremely difficult, so only a few specimens of each have ever been seen by researchers. Interestingly, these heavier elements have completely different nuclear properties from their lighter counterparts. It's likely that their atomic and chemical properties are also significantly different. Recently, scientists have conducted chemistry experiments on single atoms and there are indications that, at the far end, the periodic table might not continue as previously thought.

It's clear that a nuclear physicist's work can never be considered complete. There will always be new problems to solve and discoveries to make and, as our understanding develops, so too do the opportunities within the field.

CHEMICAL ELEMENTS IN A (VERY SMALL) NUTSHELL

Chemical elements are substances that cannot be broken down into any other substance. Each element has its own type of atom, which is why each chemical element is different from the others. Everything in the Universe contains atoms of at least one or more elements, and 118 elements have been identified so far. Ninety-four of these occur naturally on Earth, while the remaining 24 have been created artificially.

Atoms are made up of a nucleus that contains protons and neutrons, surrounded by electrons in shells. It is difficult to comprehend just how small an atomic nucleus is, but it is much smaller than the width of a human hair and a typical bacterium. The nuclei of all atoms contain subatomic particles called protons. Hydrogen is the only element that contains protons but not neutrons in its atomic nucleus. In fact, hydrogen contains a single proton. To build other elements, neutrons must be added to their nuclei because, without neutrons, further protons cannot be added.

Protons are subatomic particles with a positive charge and a relative mass of 1, and neutrons are uncharged subatomic particles with a mass of relative to a proton.

Remember: protons are positive, and neutrons are neutral.

ASK DR JACEK DOBACZEWSKI

WHO INSPIRED YOU TO STUDY PHYSICS AT UNIVERSITY?

Certainly my high school teacher. He conducted the most unusual and untypical classes in the entire school. He pointed us towards problem solving that inspired some spectacular, sometimes explosive, experiments! I remember one class where we estimated forces acting on an iron bar that was fixed at its ends and cooled by dry ice. It snapped with the most horrible noise and finding out why was the most interesting journey into the structure of metals.

DO YOU TEACH AS PART OF YOUR ROLE? IS THIS SOMETHING THAT YOU ENJOY?

I'm currently employed at the University of York on a research grant, so I don't currently teach. However, I have taught for around 40 years during my professional career, so I would say I've had a good dose of teaching experience. I enjoyed teaching, but I gradually stopped enjoying the amount of time it takes.

WHAT HAS BEEN THE HIGHLIGHT OF YOUR CAREER SO FAR?

As a young postdoc, I solved the problem of how to describe nuclei built of many more neutrons than protons. Even now, I'm probably best known in the community for this early success. Since then, I've been offered a variety of opportunities to build and lead large research groups, which has allowed me to propose and realise ideas that couldn't be addressed without teamwork. This is what I do now – try to develop methods that enable us to describe properties of heavy nuclei with previously unavailable precision.

YOU'VE SPENT MOST OF YOUR CAREER AT THE UNIVERSITY OF WARSAW BUT HAVE SINCE MOVED TO THE UK. CAN YOU DISCUSS THESE EXPERIENCES IN MORE DETAIL?

It's true that I've spent most of my career at the University of Warsaw, but also a very large chunk outside Warsaw. I think around 30% of my career has been spent working abroad, so I would rather call myself an ambulant physicist – not an atypical professional profile these days, at all. I really love moving to new places and embracing new challenges, and York has satisfied both.

WHAT DO YOU FIND MOST FASCINATING AND EXCITING ABOUT THIS PARTICULAR AREA OF PHYSICS?

I am a big fan of having a philosophical approach to physics and science in general, which sees "emergence" as the basic principle of nature. This approach says that the whole is always more than a mere sum of its constituent parts. For instance, a living organism is the sum of its biological cells, but its essential features are well beyond what the properties of cells can tell us.

A biological cell is a sum of simple organelles, but its functions in life emerge as something much more than a sum of its membrane, cell nucleus, mitochondria or chloroplasts. The proteins inside the cell are so much more than the sum of the constituent atoms. This chain of emerging phenomena continues down to smaller and smaller objects, and the atomic nucleus exhibits fascinating quantum phenomena that emerge well beyond what its fundamental constituents, protons and neutrons can tell us. To me, the questions of how protons and neutrons are organised within the atomic nucleus is the principal scientific problem and is worth spending a lifetime of research on.

FINALLY, DO YOU HAVE ANY WORDS OF WISDOM REGARDING A DAY IN THE LIFE OF A PHYSICIST?

Well, first, I want to say that being a scientist – and, in particular, a physicist – is an extremely pleasant and rewarding way of spending one's time in this world. The freedom to organise your time and life is incredible; these are never 9-to-5 jobs. Working in physics is a pleasure and it's something that never stops – you can do your thinking wherever you are and whatever you're doing. It's said that the best ideas come in the shower, so I recommend taking a shower five times a day!

You get to work with some extremely bright people, and you have fantastic help and support from your supervisors and colleagues. Of course, there are downsides, too. It's an extremely competitive environment; getting a stable job situation is difficult and a stability in life is not easy to attain. But, hey, it worked for me – why wouldn't it work for you, too?

Find the article online and download the activity sheet: https://futurumcareers.com/the-atomic-nucleus-greater-than-the-sum-of-its-parts

JACEK'S TOP TIPS FOR STUDENTS

1. If you're curious about how the world works, then physics is for you!

2. Physics is an extraordinarily broad subject, with something for everyone.

3. Tailor your particular interest into a specific branch of physics.

- If you want to know how physical properties influence life, or why the brain uses quantum mechanics, then study biophysics.
- Astrophysics will help you understand more about gravitational waves.
- Nuclear physics can be used to solve the nuclear waste problem.
- Ultimately, physics can be studied for its own sake - it doesn't need to have a specific aim in mind!

OPPORTUNITIES IN NUCLEAR PHYSICS

- According to the Nuclear Skills Strategy Group, the UK will require approximately 111,000 full time employees by 2021
- Many UK universities work collaboratively with the nuclear sector. The Nuclear Institute has further information on some opportunities, as well as a range of approved apprenticeship schemes
- The 27th International Nuclear Physics Conference will be held in Glasgow, UK, 29 July to 2 August 2019
- According to PayScale, the average salary for a nuclear physicist is around £77,000

Jacek and his research team at the University of York

101 THINGS TO SEE IN SPACE – AND ALL FROM YOUR LIVING ROOM

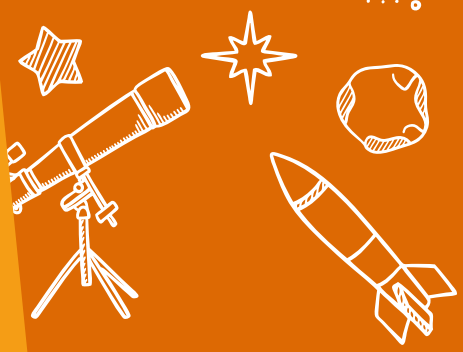
WHAT IF WE COULD ALL EXPLORE SPACE LIKE THE CREW OF THE STARSHIP ENTERPRISE? THE **NATIONAL SCHOOLS' OBSERVATORY** IS GIVING EVERYONE THE CHANCE TO DO JUST THAT WITH THE WORLD'S LARGEST ROBOTIC TELESCOPE – AND IT SENDS IMAGES OF PLANETS AND GALAXIES TO THE PEOPLE WHO USE IT

IMAGINE THIS

What do you see when you look up at the night sky? Just a bunch of stars and the Moon? Maybe you can see the Big Dipper or Ursa Major. How about Orion?

Whether you can recognise and name the constellations or not, it's pretty certain that at some point in your life, you'll have looked up at the sky at night and wondered at the full Moon or the twinkling North Star. Imagine, though, being able to look closer.

Imagine using the largest robotic telescope in the world and receiving pictures. What would you see? Sign up to the National Schools' Observatory and you'll find out: www.schoolsobservatory.org/futurum



As technology becomes more sophisticated, scientists all around the world are looking deeper into space. Not only are they finding new planets, they're investigating the most massive explosions in the Universe, and tracking ripples in space time caused by gravitational waves. Astronomers – scientists who study objects in the sky such as black holes, planets and galaxies – might have a degree in astrophysics or maths, but the National Schools' Observatory (NSO) is enabling everyone to become an astronomer – and, yes, that includes you!

WHAT IS THE NSO?

The NSO is a free, online tool that gives people access to the Liverpool Telescope, both of which are run by Liverpool John Moores University. The aim is to use the wonders of space to inspire young people – you – to develop an interest in science, tech, engineering and maths (STEM) and to understand how these subjects can be applied to real-world applications. Although targeted at students and teachers, anyone can take part regardless of their age, background or where they live.

WHAT IS THE LIVERPOOL TELESCOPE?

The Liverpool Telescope is the largest robotic telescope in the world! In spite of its name, the Liverpool Telescope isn't based in Liverpool, UK; it's actually located on the island of La Palma in the Canary Islands, off the coast of Africa. This small, volcanic island has a much more reliable climate than Liverpool, which is important because the telescope can only work in clear and dry conditions.

There's a small weather station attached to the telescope and this records temperature, humidity, wind speed, cloud coverage and barometric pressure. Depending on the results, this information signals the telescope to open or close. Luckily, the conditions on La Palma are usually good, and the telescope is generally open 80-90% of the year. But if there is snow or dust blowing over from the Sahara Desert, for example, the telescope will remain closed.

WHO USES THE LIVERPOOL TELESCOPE?

Professional astronomers use the telescope for 90% of the time. The remaining 10% is set aside for people like you – you just have to register. Dr Stacey Habergham-Mawson from Liverpool John Moores University in the UK is the chief astronomer working on the NSO project, and she – with her colleagues – are keen to open the Liverpool Telescope and the NSO to people everywhere and to all sections of society. For example, their videos have been translated into British Sign Language to improve accessibility.

WHAT CAN BE OBSERVED THROUGH THE TELESCOPE?

"Professional astronomers can apply for time on the telescope to measure a range of things," says Stacey, and these include:

- Photometry (measuring the intensity of light)
- Spectroscopy (breaking the light down into different wavelengths that correspond to different chemical elements)

Find the article online and download the activity sheet: https://futurumcareers.com/101-things-to-see-in-space-and-all-from-your-living-room

- Polarimetry (investigating the direction of light that hits the telescope from astronomical objects).

These are all complex subjects, but registered users who aren't professional astronomers can observe the Moon, planets, star clusters, nebulae (dusty objects associated with the life or death of a star) and galaxies. In fact, the NSO has produced a catalogue, from which it's possible to choose from several hundred astronomical objects to observe! Not only that but users can take images of these objects with the telescope's photometry function.

DO YOU HAVE TO GO TO LA PALMA TO USE THE TELESCOPE?

Although the telescope is based in La Palma, registered users don't need to go there. The idea is that people send the telescope a set of instructions. Of course, large telescopes such as this are extremely complex, so users are guided through the observation process. This ensures that the telescope doesn't break; for example, pointing the telescope at bright objects in space for too long will damage the instrumentation.

WHAT HAPPENS AFTER THE TELESCOPE HAS RECEIVED INSTRUCTIONS?

Depending on the instructions it receives, the telescope will send back an image known as a FITS file. This file type has various advantages over a normal image file, such as jpeg, because they can be manipulated; they allow accurate measurements of the light emitted from astronomical objects; and they allow the user to access "hidden" information such as weather conditions at the time the image was taken, the position of the object in the sky or how far away the object is. "What's exciting is that people can do science with the image, just like the professionals," says Stacey.

Imagine creating colour versions of the images and taking specific measurements such as the size, the colour or the brightness of an object.

- Knowing the size allows you to compare different astronomical objects and relate them to known objects like the Earth or the Sun.

- Discovering the colours provides information on the age of the object or the chemical composition of gas.

- Exploring the brightness allows you to compare stars in a system and work out how old the object is.

To open these FITS files, special software is required. Luckily, an easy-to-use version has been developed by the NSO team. Known as LTImage, the software can be downloaded for free, giving you all the tools you need to become an amateur astronomer.

DR STACEY HABERGHAM-MAWSON

Manager of the National Schools' Observatory (NSO)
Astrophysics Research Institute
Liverpool John Moores University, UK

FIELD OF RESEARCH

Astrophysics

RESEARCH PROJECT

The NSO is an online outreach project that gives people across the globe access to the Liverpool Telescope, the world's largest robotic telescope. Users can program the telescope to take images of astronomical objects, which can be manipulated to give measurements and chemical compositions.

FUNDERS

Liverpool John Moores University; Science and Technology Facilities Council, Grant No. ST/R000344/1

WEBSITE

www.schoolsobservatory.org/futurum

The Liverpool Telescope in its open enclosure at the observatory site in La Palma © Liverpool Telescope Group

ABOUT ASTROPHYSICS

Astrophysicists use their knowledge of physics and chemistry to study astronomical objects like planets, galaxies, the Sun and other stars, moons and nebulae. Essentially, astrophysics involves making observations and creating theories from these observations.

"There are so many reasons that young people should be interested in astrophysics," says Stacey, "It allows you to be curious and ask questions, and begin to understand the way our world works and the fundamental laws that govern the entire Universe. There are also more practical reasons. Studying any type of physics gives you so many skills – numeracy, communication, logic, computing are just some of these – and you can apply these skills to tackle the world's biggest problems, whether that's in space or here on Earth. People with these skills, and a drive to do something with their lives, can really change the world."

A degree in astrophysics can lead to many different careers. Some people continue working in the field, but others use the skills they have developed to pursue other careers in computing, finance, medicine and engineering, for example.

"In the UK, physics graduates generally earn more over their working life compared to most other degrees and are less likely to have periods of unemployment." says Stacey "So, you're learning about something exciting, and simultaneously gaining the skills to open many doors to future employment."

OPPORTUNITIES IN ASTROPHYSICS

- The National Schools' Observatory runs an annual work-experience week for 16-18 year olds in July
- The University of Kent runs an annual Space School for 15-18-year olds in August
- The University of Leicester runs a Space School annually for both 13-15 year olds, and 16-18s
- Astrophysicsgirl keeps an up-to-date, global list of summer schools in astrophysics
- Find out more about careers and work experience on the SpaceCareers website
- The average salary for an astrophysicist in the UK is £50-60K, but this varies widely in different sectors (academia / industry) and depends on experience

A mosaic of the full Moon taken by the National Schools' Observatory © National Schools' Observatory

Rosette Nebula © National Schools' Observatory

ASK DR STACEY HABERGHAM-MAWSON

DID YOU ALWAYS WANT TO BE AN ASTROPHYSICIST?

No – I didn't know what I wanted to be when I was younger. I had no idea that this existed as a job. I was the first (and so far, only) person in my family to go to university and, as a child, I decided that that was what I wanted to do.

When I was 16, I started to wonder about what I would study. I got advice from a teacher to study something I was interested in so I applied for astrophysics because I thought space was really cool, and it was the part of physics that interested me most. When I started at university, I learnt more about the topic and I became hooked!

DO YOU HAVE TO BE GOOD AT A PARTICULAR SUBJECT TO STUDY ASTROPHYSICS?

Traditionally, all university courses (certainly in the UK) require students to be good at physics and maths. However, I'm always keen to show young people that the story doesn't end there. Many people working in astronomy don't necessarily have traditional backgrounds. I dropped maths in school because I didn't see the point of it. You can always find a way; I did extra maths courses at university to get me up to the same level as everyone else.

Also, many people working in this field have backgrounds in engineering or computer science – and don't always have degrees. There are limitless possibilities if you have a drive to do something. We all follow different paths.

DO YOU THINK THAT WE WILL FIND LIFE ON OTHER PLANETS?

Yes – statistically it's possible. We now think that almost every star hosts a planet, and we've discovered over 4,000 exoplanets in our galaxy, alone! The chances are, though, that if/when we find life it'll likely be bacterial life. I don't think that we'll ever "meet" another life form like us – there are too many coincidences we'd need for that to happen. We'd need them to be close enough to Earth to be able to communicate; we'd need them to have evolved enough to send communications or travel; and we'd need them to have done this at the same time as us. Life is short on the timescales of the Universe, and the distance between objects in space is unimaginable: Light takes 8 minutes to reach us from the Sun, and 4 years from the next closest star – and that's travelling at 300,000,000 metres per second! So, I don't think we'll have aliens knocking on the door, but I do think we'll find evidence of life elsewhere.

WHAT MOTIVATES AND INSPIRES YOU?

I'm motivated by giving back. I know that physics is sometimes seen as being really hard and only suitable for certain groups (mainly well-off men), but the more I studied and worked, the further in my career I went. I'm not saying it's easy, but it is doable.

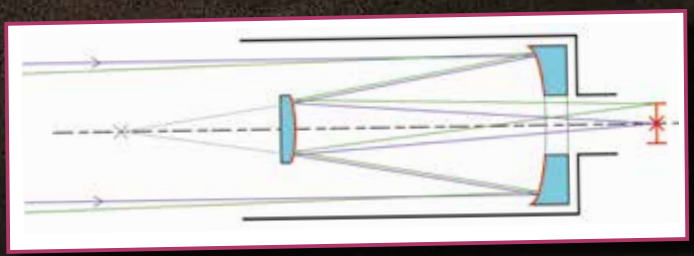
I know lots of people who would have been able to do the same thing, but we don't all have the same opportunities in life. Many have to face an inordinate number of hurdles, put in their way by circumstance or other people. I want to try and make sure that I use the advantage I've been given to help pull other people over the hurdles.

I do a lot of work in equality and diversity, and I work with young people to inspire them and raise their aspirations. This is what motives me – trying to make the world a little more equal in whatever small way I can.

WHAT OTHER INTERESTS DO YOU HAVE?

I've been a vegetarian since I was 11 and am very interested in how we can help the planet. I drive an electric car and always strive to learn more about renewable energy and technological advancements in my area. I love animals and gardening – I like to grow my own fruit and veg – and I generally like being in the countryside.

My husband and I honeymooned in New Zealand, spending three weeks in a campervan and travelling around. I love almost everything about the country: we hiked on a glacier, swam with wild dolphins and did a skydive! I just love being in nature. I'm probably boring to most people, but I like what I like, and I know that those close to me like me for who I am.



HOW DO TELESCOPES WORK?

Telescopes collect and focus light from the night sky using either curved lenses (refracting telescopes) or mirrors (reflecting telescopes), or a combination of both. The bigger the lens or mirror, the more light the telescope can gather. A big telescope is therefore a big advantage!

The Liverpool Telescope uses mirrors: a huge, 2m diameter primary mirror reflects light onto a smaller secondary mirror, which focuses the beams of light onto a set of instruments. These include cameras to take images, and spectrographs which record the different wavelengths of light reflected onto them.

HOW TO BE A STAR

JON CHASE STUDIED AEROSPACE ENGINEERING BEFORE BECOMING A RAP STAR, BUT NOT JUST ANY RAP STAR: HE RAPS ABOUT SCIENCE ON RADIO, TV AND IN SCHOOLS. STUDY SCIENCE, TECH, ENGINEERING AND MATHS (STEM) AND YOU COULD OPEN DOORS TO THE UNIVERSE, TOO

WHEN DID YOU START RAPPING ABOUT SCIENCE?

I wrote a random rap about the scientific method and, many years later, I rapped it to my professor on the way to an astrobiology conference. He suggested I rap it to one of the organisers, who happened to work for NASA's Astrobiology Magazine. She asked me to write a rap for them. That astrobiology rap and video became my first science rap, back in 2008. By then, I was completing an MSc in Communicating Science.

HOW DID RAPPING ABOUT SCIENCE BECOME A CAREER?

The following month I wrote some more raps to perform alongside my professor at various venues. Some were performed at a school and others were performed with my professor at the first ever Science Museum Lates event in London. The publicity from this event, alongside my rap for NASA, catapulted me onto national TV, radio and in international newspapers! This is when my existence as a UK science rapper really took off – especially on the internet.

WHAT HAPPENED THEN?

Requests soon followed for science rap-related activities such as workshops and bespoke raps. Rapping about science became my niche within science communication. It was also the topic of my final dissertation.

DO YOU THINK THAT COMMUNICATING IDEAS VIA RAP MAKES SCIENCE MORE ACCESSIBLE?

I'd like to think so. Linking information to people's own interests and experiences can make it easier for a person to engage with it. Generally, it's about finding different ways to relate with the audience. I use rap as a vehicle to ease communication, but it could be anything else that a person's into: movies, games, music or some other pastime.

IS IT DIFFICULT TO MAKE YOUR RAPS FUN WITHOUT DUMBING DOWN THE SCIENCE?

People like raps for different reasons so I guess it mainly depends on the audience. A scientist or student might find my raps fun because I'm accurately rhyming about things they're familiar with. Then there are some people who are just happy that they're watching a performance from a rapper.

As a rapper, my role is to fit words onto a beat or rhythm in a way that appeals to the listener. As a science communicator, my role is to pitch scientific information in a way that suits the people I'm talking to. I don't necessarily see it as dumbing down, but rather as saying things in a way that helps people to engage.

For example, my most popular rap is about the periodic table, which literally drops the scientific information! There's only a limited amount of time to get a message across, though, so people can't use rap to get a deeper understanding of a subject. I suppose that's what the education system is there to provide.

ABOUT JON CHASE

Freelance science communicator and professional science rapper

CV

BEng in Aerospace Technology, Kingston University, UK
BSc in Science and Science Fiction and MSc in Science Communication, University of Glamorgan, UK

ABOUT RAPSCIENCE

"Rapscience is a play on words, as in to rap (talk freely and frankly) about science whilst also rapping (lyrics) about science. I basically use science-based raps alongside informal and relaxed conversations to talk about science and scientific issues. My audience includes all ages, from reception to retirement. However, the majority of my material is aimed at Key Stage 2-5"

www.rapscience.co.uk

WHAT HAS BEEN YOUR FAVOURITE RAP PROJECT SO FAR?

Putting together a hip hop event for Manchester Science Festival as part of the Josh Award, which I received in 2017. It was amazing to be able to develop an event where the public could listen to science raps from the UK and US, engage with the science of how turntables work, and play with some augmented reality science graffiti pieces.

YOU HAVE A DEGREE IN AEROSPACE ENGINEERING. WHO, OR WHAT, INSPIRED YOU TO STUDY STEM (SCIENCE, TECH, ENGINEERING AND MATHS) SUBJECTS?

To be honest, I think it was probably science fiction! I wanted to be the scientist with all the answers, or the inventor who could create the impossible in their shed or basement. I wanted to build spaceships and invent other cool stuff like hover boards and flying cars (which I ended up investigating for the final project of my aerospace degree).

The Back to the Future movies had a huge influence on my imagination as a young kid. I actually wanted to be more like Doc Brown than Marty Mcfly (and more like Q than James Bond). I was also pretty good at maths as a kid, so the thought of solving problems has always felt like more of a game than a challenge. So, naturally, STEM subjects attracted me the most.

WHY DO YOU THINK YOUNG PEOPLE SHOULD STUDY STEM?

We're living in a world that's mostly built on STEM. Our travel, communication, healthcare, housing all put us up close and personal with STEM in some shape or form. However, for many, STEM learning stops after secondary school. I think it's important to help young people to better engage with STEM when they're at school i.e. when it's mandatory. A positive relationship with something at an early age can stick with you for your whole life and affect the way you view and understand the world.

WHAT 'S YOUR MESSAGE TO YOUNG PEOPLE?

Be prepared to immerse yourself in your interests and keep an eye out for others who are successful in the career you'd like to have. Work experience is brilliant if you can get it, but nowadays people have quite a bit of freedom to set up their own company or business. You just have to be really into what you're doing so commitment doesn't become an issue.

Also, know what you want out of a job. Is it for the money, the status, the responsibility, the impact, etc.? Not getting what you want/need from a job can affect your job satisfaction and how long you stay in the job. I loved talking about science; now I'm a science communicator. I feel rewarded every time I get to do a talk, show or workshop, and especially when I hear from people who have found my stuff useful.

So, basically, if you want to do something then get involved and don't be afraid of challenges or mistakes. They're the things that help us grow the most.

A WORKING-CLASS HERO IS SOMETHING TO BE

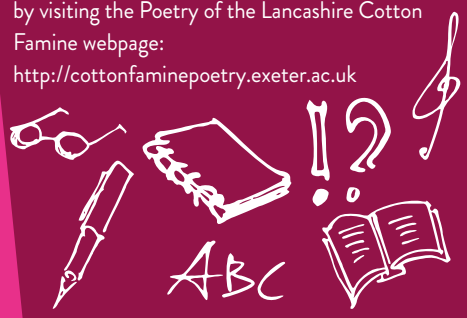
DR SIMON RENNIE IS INVESTIGATING VICTORIAN POETRY – SPECIFICALLY THAT FROM THE LANCASHIRE COTTON FAMINE. BY UNCOVERING TEXTS THAT HAVE LAIN DORMANT FOR MORE THAN A CENTURY, WORKING-CLASS VOICES ARE BEING HEARD AGAIN. AND WHAT THEY HAD TO SAY THEN IS JUST AS PERTINENT TODAY

'SETTLING TH'WAR' BY WILLIFFE CUNLIAM

Dr Simon Rennie's research has uncovered around 700 poems from the Lancashire Cotton Famine. There are obviously many highlights, given the huge number of poems in the collection, but Simon's personal favourite is a dialect poem from Burnley called 'Settling th'War' by Williffe Cunliam (really a blacksmith called William Cunliffe).

It describes the bigwigs of a Lancashire town ('chaps wi' noddles full o' larning') discussing the American Civil War as though they could have any effect on it. It's funny because it ridicules the situation, but also poignant because it highlights the helplessness people felt in the region as their hardship was caused by events thousands of miles away.

You can look at 100 of the poems now and keep an eye out for the later inclusion of the next 600 by visiting the Poetry of the Lancashire Cotton Famine webpage: http://cottonfaminepoetry.exeter.ac.uk



The Lancashire Cotton Famine was a period of extreme economic hardship for working-class people in the North of England between 1861 and 1865. It was caused mainly by the American Civil War, and when the Union (North) blockaded goods being exported from the Confederacy (South), cotton stopped arriving at the mills in Lancashire, and half a million people lost work almost instantly. Slavery was a major factor in the war, and the cotton was worked by slaves in the southern states of America.

Although people in the North of England mostly opposed slavery, they suffered terribly when their factories ran out of cotton. Many families experienced hunger and malnutrition as the work dried up, and it was some time before adequate charity and relief efforts kicked in and their suffering was alleviated. It is estimated that the Cotton Famine affected almost 20% of the UK population.

Now, Dr Simon Rennie, based at the University of Exeter, is working to uncover the poetry of the Lancashire Cotton Famine, and in doing so, making many working-class voices from the period heard for the very first time.

WHAT IS THE POETRY OF THE LANCASHIRE COTTON FAMINE?

During the Lancashire Cotton Famine, thousands of poems were written. Many of these poems were written by working-class people, who used poetry as a medium through which they could document their thoughts and feelings regarding political and social events of the day.

Simon's interest in the poems came about because nobody had ever written about them before. "My previous research had been into poetry of the Chartist period, which was the generation before (1838-1848), so I already had a strong interest in working-class poetry of the Victorian era," explains Simon. "The idea that nobody had read these poems before excited me: searching for unread poems is like digging for treasure."

In the course of his research, Simon has come to realise that the works can tell us interesting things about the historical context of the Lancashire Cotton Famine.

WHY IS IT IMPORTANT TO INCREASE PUBLIC KNOWLEDGE OF THE LANCASHIRE COTTON FAMINE?

Although things are improving now, there has not been anywhere near enough attention paid to working-class literary production in the nineteenth century, and this means that things like the Lancashire Cotton Famine are only understood from incomplete sources. If we can understand what ordinary people thought

DR SIMON RENNIE

Senior Lecturer
University of Exeter, UK

FIELD OF RESEARCH

Victorian Poetry

RESEARCH PROJECT

Simon's work focuses on poetry from the Lancashire Cotton Famine – texts which have lain dormant for over a century. The project looks at social class, because many of the poems represent working-class voices reacting to a major economic crisis – voices that are being heard for the very first time. As well as recovering a hidden history, Simon is making these voices available to the general public.

FUNDER

Arts and Humanities Research Council

about the famine through their poetry, then we gain a broader, deeper historical view of its effects.

There is a lot of talk now about the global economy, but this is an early example of a failure of global capitalism. Countries have relied on each other for their financial well-being for centuries. This is a global event that deeply affected almost a fifth of the population of the UK, but many people, even quite well-educated people, have barely heard of it.

HOW WERE THE POEMS 'RE-FOUND' AFTER ~150 YEARS?

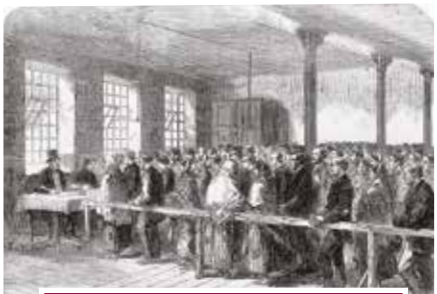
It is sometimes not recognised that by far the largest publishers of poetry in the nineteenth century was the network of local newspapers. In Lancashire, which had a very high population density because of the Industrial Revolution, almost every town had two newspapers, and they would usually publish at least one poem every week. When you add all these together there are thousands of poems, and many of them discuss current affairs or their concerns.

"The British Library holds some of these newspapers in digital or hard copy form, but so do local libraries, often as microfilm versions. Because poems look different on the page to prose articles, they are easy to spot," says Simon. "It is simply a matter of reading them and working out their subject matter."

WHY IS IT IMPORTANT TO UNCOVER THESE PREVIOUSLY HIDDEN VOICES?

The voices contained within the poems tell us something about the times in which they were written and provide a fascinating insight into what ordinary people felt and thought. One of the most exciting aspects of Simon's research is that there are bound to be countless other areas of research that can uncover voices that are currently lying dormant. The voices are there – you just need to find them.

The spirit of charity



The cotton famine, Manchester, 19th century

The distress

ABOUT VICTORIAN POETRY

Victorian poetry is poetry that was written in England during the reign of Queen Victoria (1837-1901). While poets such as William Blake and John Clare are well known, not many nineteenth century working-class poets have been given the attention they clearly deserve. There were very many working-class poets who wrote fine poems during the Victorian era, but they were often not published in books or collections, or celebrated in their own lifetimes.

WHAT CAN STUDYING WORKING-CLASS VICTORIAN POETRY SHOW US?

Working-class Victorians were more literate and literary than many people imagine, and their poetry is often revealing of their attitudes towards what was going on socially or politically. They wrote poetry because poems can be written quite quickly, and they had little time for anything else. Because working people had very few alternative ways for recording their thoughts, working-class Victorian poetry gives us a unique insight. When reading it, it can feel like someone has taken a microphone back into the past and listened in on the conversations of long-dead, ordinary people. By listening to these voices from the past, society can learn that future challenges often have echoes in history, and these can play a part in informing the decisions we make in response to them.

WHY SHOULD YOUNG PEOPLE STUDY ENGLISH AND POETRY?

Literature is humanity listening to itself. If human beings do not hear what a range of other human beings have to say, then they do not have the kind of full understanding necessary to make fully informed decisions about the way forward in society. The study of English literature at degree level teaches critical thinking – the ability to evaluate any given situation in a more rounded and complete way. Poetry condenses complex thought and feeling, which can be very useful for quickly conveying ideas. It also "defamiliarises" – makes ordinary things seem strange. This is a really important way of helping people to constantly reassess the world around us. It stops us becoming complacent.

HOW CAN WE ENCOURAGE MORE MEN TO STUDY ENGLISH?

English is a female-dominated area of undergraduate study research, and there have been various studies on this and various suggestions as to how to address it. One suggestion is to increase the amount of "male-centred" texts on syllabuses. But perhaps this gendering of texts is what might need to be challenged in the first place. Good male and female novelists create complex male and female characters, and poetry also is capable of speaking to a broad variety of the population.

WHAT CAREER OPPORTUNITIES ARE AVAILABLE WITH AN ENGLISH DEGREE?

Any career path that requires communication, written or verbal, is enhanced with a good literary education. Many of the most influential people in the worlds of politics, business, law and education began their careers with an English degree. Simon frequently writes references for former students who enter into all sorts of professions, because an English degree is one of the most flexible bases for higher learning. An increasingly diverse economy, with more emphasis placed on cultural capital rather than manufacturing, requires a highly educated, flexibly skilled population.

OPPORTUNITIES IN ENGLISH

- An English degree is one of the most transferable degrees you can study, where the skills you gain are useful in most job sectors
- The English Association has loads of information on the English language and its literatures, with an aim to foster good practice in the teaching and learning at all levels
- *Times Higher Education* has an entire section of its site dedicated to explaining what you can do with an English literature degree

Find this article online and download the activity sheet: https://futurumcareers.com/a-working-class-hero-is-something-to-be

ASK DR SIMON RENNIE

WHO OR WHAT INSPIRED YOU TO STUDY ENGLISH AT UNIVERSITY?

I had always been a big reader, but for various reasons I didn't achieve anything at school or sixth-form college. When I was in my late thirties, I was lucky enough to meet someone who inspired me to get into university, and with her encouragement and support I managed to stick with the subject through three separate degrees and to end up teaching and researching it.

DID YOU ENJOY WRITING POETRY AS A CHILD?

I did, but I'm not sure how good it was. I honestly think that the more poetry one reads, the more chances one has of writing good poetry. When I think back, I did not read nearly enough poetry. The way poetry is taught at schools now is much better than when I was younger, and so young poets produce better work. I am constantly surprised by the very high quality of poetry that young people such as my students at the University of Exeter produce.

HAVE YOU ALWAYS WORKED IN ACADEMIA?

I worked in factories and warehouses in Manchester for twenty years before I ever set foot inside a university, and I never dreamed that I would ever get the opportunity to do what I do now. Although I was clearly quite clever – and well-read – I had no real intellectual ambition until I met someone who believed in me. This should be a lesson to anyone, I think, that many people are capable of achieving what they have never even considered possible.

WHAT HURDLES HAVE YOU HAD TO OVERCOME IN THE COURSE OF YOUR CAREER?

I thought that my industrial background and my accent – which is quite unusual in this line of work – would be hurdles, but they honestly have not been. In academia, if you produce results, people do not care where you have come from. Whether it is research or teaching, often it is something of an advantage to be a little out of the ordinary.

FINALLY, IS THERE ANYTHING YOU WISH YOU HAD KNOWN WHEN YOU WERE STARTING OUT ON YOUR CAREER PATH?

I was pleased to get the opportunity to teach and to carry out research, but I hadn't fully appreciated that the element of my job that involves helping young people through sometimes challenging times in their lives would also be so rewarding. Or that I would feel such a sense of shared kinship with my academic colleagues. Universities are like little towns or big families, and it has been an unexpected pleasure to feel that we are often all pulling in the same direction and helping each other out when need be.

SIMON'S TOP TIPS FOR STUDENTS

1. To write good poetry, you must read as much poetry as possible. If you're a budding poet, devour as much as you can!
2. Many people can achieve things they never thought possible, so open your mind to possibilities and you never know what might happen.
3. There are bound to be other areas of research that can rediscover what ordinary people thought about historical events. Who knows, perhaps you could be the one to uncover them!

SAY IT WITH A SONG

Simon has been working with a traditional music group called Faustus, who have adapted some of the working-class Victorian poems from his collection and put them to music in an album called 'Cotton Lords'.

"The link between poetry and song was much closer in the Victorian period than it is today." explains Simon. "Some of the poems were intended to be sung, and some even suggested the tune they should be sung to."

You can listen to "Food or Work" sung by Faustuson the University of Exeter's website.

CHIZOBA OBI

PhD in Economics
University of Glasgow, UK

CURRICULUM VITAE

15 GCSEs Grade C and above (Maths B B; Double Science B B)

A Level: Maths B; Economics C; Psychology C

AS Level: Business Studies B

First class BA Hons in Economics, University of Manchester

MSc in Economics and Industrial Organisation, University of Warwick

Chizoba with her mum on graduation day

WILL THIS BE THE ECONOMIST THAT HELPS DEVELOPING COUNTRIES MANAGE THEIR DEBTS?

CHIZOBA OBI HAS JUST BEEN AWARDED HER PHD IN ECONOMICS AT THE UNIVERSITY OF GLASGOW, AND IS HOPING TO USE HER KNOWLEDGE TO HELP DEVELOPING COUNTRIES MANAGE THEIR DEBTS – SOMETHING SHE WOULD NEVER HAVE IMAGINED DOING WHEN SHE WAS AT SCHOOL

WHAT DID YOU WANT TO BE WHEN YOU WERE YOUNGER AND WHY?

When I was about 12-13 years old, I wanted to be an accountant. I preferred maths to English and science because I liked calculations and solving problems; but there might have been a family influence, too. My family is very maths-orientated and I wanted to be a business woman like my mum. She runs her own courier business in Nigeria, and I was fascinated by how she managed family life alongside her business interests.

SO, YOUR MUM WAS A STRONG ROLE MODEL FOR YOU, THEN.

Yes! I saw that she enjoyed her work and I sought to help her in many ways, including exchanging sums of money with customers and calculating profits. Given the difficult environment of doing business in Nigeria (poor infrastructure is one example), she had to find ways to overcome many challenges. I remember her always having a plan B – and C!

YOU GOT A C FOR ECONOMICS, AND A B FOR BOTH BUSINESS STUDIES AND MATHS AT A LEVEL. WHY DID YOU CHOOSE TO STUDY ECONOMICS AND NOT BUSINESS STUDIES OR MATHS AT UNIVERSITY?

I actually started doing a business economics degree, but half way through the course – in my second year – I realised I was enjoying the economics modules more than the business modules. And my economics grades were better, too. So, I changed my degree to economics.

WHY DID YOU CHOOSE THE UNIVERSITY OF MANCHESTER?

I wanted to go to a university that was rated the best for economics. But I didn't just go for the top five universities in the UK; I targeted the top 20. Manchester was in the top 20 at the time. Lots of my friends went there, but I was also drawn to its student lifestyle, performance ratings, its Economics Society and its Trade & Investment Society.

AFTER YOUR MASTER'S DEGREE AT THE UNIVERSITY OF WARWICK, YOU WORKED IN LONDON FOR TWO YEARS. WHY DID YOU CHOOSE TO GO BACK AND STUDY FOR A PHD AT THE UNIVERSITY OF GLASGOW?

I wanted to carry on working on my master's thesis in sovereign debt, and I eventually chose the University of Glasgow because of the resources it provides. The economics department holds weekly workshops with external speakers, which allowed me to network with people from within the University of Glasgow and externally. It also hosts conferences, and I was fortunate to co-organise some of those with the help of my supervisors. Not only that, but Professor Sayantan Ghosal, who was my supervisor at the University of Warwick, had moved to the University of Glasgow and was interested in furthering my Master's thesis. When another professor accepted my request for supervision, it was a no brainer.

YOUR RESEARCH IS IN SOVEREIGN DEBT IN EMERGING ECONOMIES. WHAT DO YOU HOPE TO ACHIEVE WITH THIS RESEARCH?

Much of the debt owed by developing countries is in a foreign currency. So, it's very difficult for these countries to manage their debts. I'm really interested in understanding how they might address certain debt problems, and the types of debt management policies they could adopt. I hope that my research will one day enable me to give something back to countries that are in

debt distress – African states, in particular. At the moment, I'm focused on gaining experience and applying my knowledge at the Scottish Fiscal Commission, where I currently work, so that I can achieve this end goal – giving something back to my continent.

IT'S INCREDIBLY INSPIRING TO SEE HOW FAR YOU'VE COME CONSIDERING YOU DIDN'T GET AN A OR A* IN MATHS AT GCSE. WHAT ADVICE DO YOU HAVE FOR YOUNG PEOPLE WHO MIGHT BE STRUGGLING WITH THEIR STUDIES?

When I was younger, I would never have imagined that I would get a first in economics, or a Master's degree, or a PhD. I was a slow learner, and this was reflected in my results. Generally, people didn't believe that I could be academically or professionally successful. So, here's my advice: don't let your current situation or struggles define you. Never stop believing in yourself, surround yourself with hardworking people that want the best for you, dream big and work towards your dream. As the saying goes, "The one who falls and gets up is so much stronger than the one who never fell."

> "WHEN I WAS YOUNGER, I WOULD NEVER HAVE IMAGINED THAT I WOULD GET A FIRST IN ECONOMICS, OR A MASTER'S DEGREE, OR A PHD"

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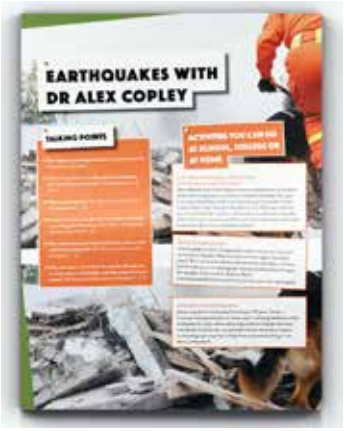
See if you can answer questions about the research in the article



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Get links to even more awesome resources

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Go online and you'll find role models working in STEAMM industries, and career and education articles aimed specifically at teachers and young people. There are so many organisations working in the STEM and STEAMM spaces that offer incredible career, teaching and education resources, as well as other exciting opportunities, for youth and educators.

www.futurumcareers.com/career-guides

Find out about professional organisations, whose aim it is to support young people and educators

Learn about the challenges the organisations are hoping address

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Access amazing resources that are designed specifically for young people or teachers

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Check out students' CVs

To start with, Chizoba wasn't brilliant at maths at school, but she liked it and worked hard. Now she's an economist working in the Scottish Government!

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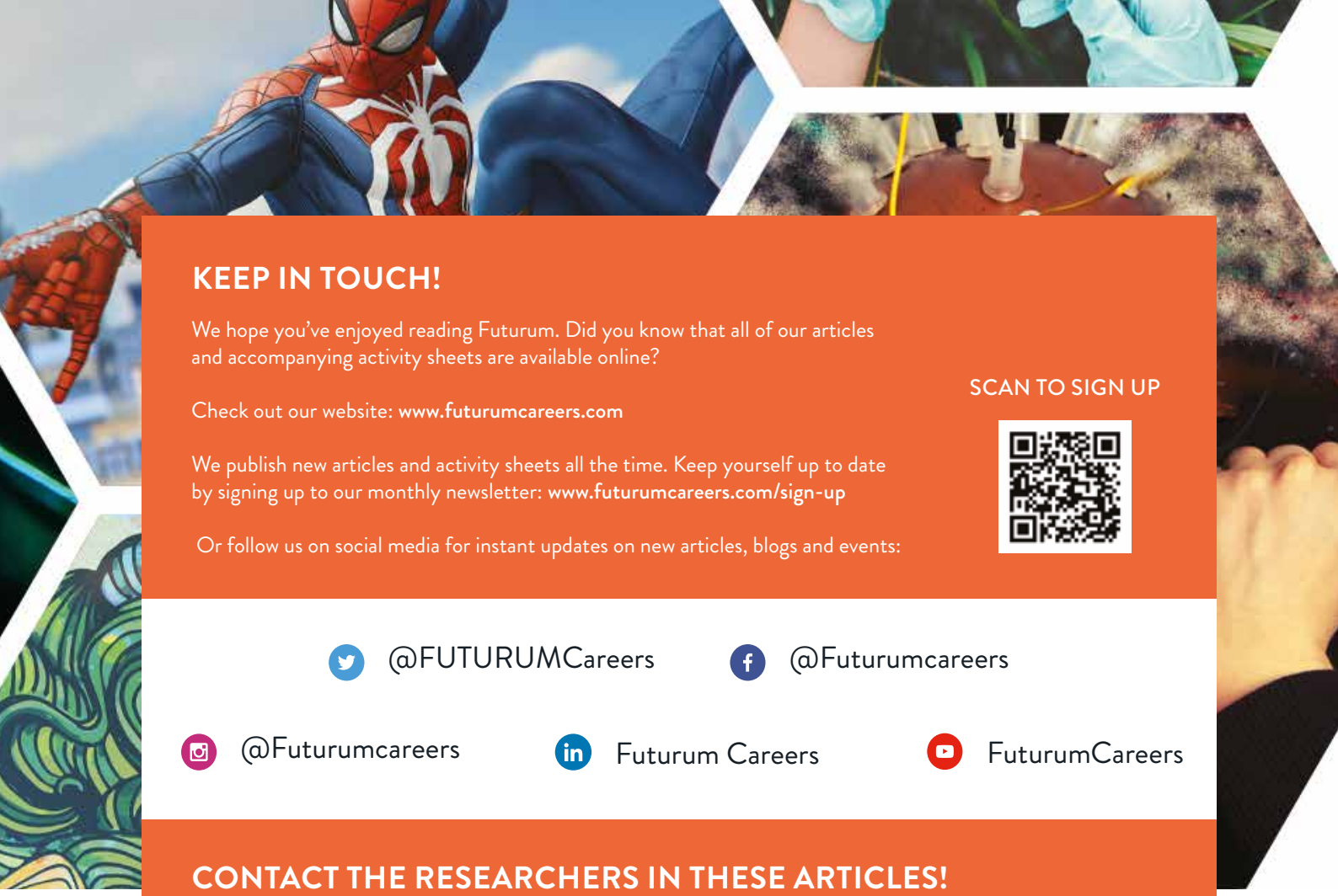

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