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A SCIENCE, RESEARCH AND TECH MAG
FOR THE NEXT GENERATION

ISSUE 3
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DO SOMETHING AMAZING. BECOME A CITIZEN SCIENTIST

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ABOUT CITIZEN SCIENCE

The New Zealand Government wants its citizens to ask questions and solve big problems. We find out why.

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DO SOMETHING AMAZING. BECOME A CITIZEN SCIENTIST

A citizen scientist? Who or what is that? According to the *Encyclopaedia Britannica*, citizen science describes "the collection and/or analysis of data by non-scientists". In other words, a citizen scientist is anyone who volunteers their time to help researchers with their research projects. These projects can be about anything: from microplastics in our water (see p 4) to biosecurity on farms (p 42) and gravitational waves in outer space (p 48), and cover the whole range of fields: astronomy, ecology, medicine, computer science, genetics, engineering....

Without citizen scientists, many research projects wouldn't get off the ground. Citizen scientists help researchers collect and explore huge data sets, which might need the involvement of thousands of people, or data from people all over the world, or to cover huge distances (imagine how difficult it would be for one scientist to collect water samples along Georgia's coastline in the US).

What's key is that citizen scientists don't need a science qualification. Anyone – and that means you – can participate, no matter how old you are or how good you are at school. And, if you're even just a teeny bit interested in learning more about space science or engineering or the environment, volunteering your time on a research project will help you understand whether a particular field makes good career sense for you. It also looks great on a CV!

You'll find two examples of citizen science projects in this mag: The Big Microplastic Survey (*See About Citizen Science*, p 6) and Gravity Spy (See *What is gravitational-wave astronomy?* p 50), but a simple internet search will have you involved in wildlife surveys, monitoring noise pollution, counting passing meteors – you name it –, a research project that is just right for you!

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MICROPLASTIC POLLUTION: HOW BAD IS IT AND WHAT CAN WE DO TO SOLVE IT?

BASED AT THE **SKIDAWAY INSTITUTE OF OCEANOGRAPHY** AND THE **UNIVERSITY OF GEORGIA MARINE EXTENSION** IN THE US, **PROFESSOR JAY BRANDES** AND **DODIE SANDERS** ARE INVESTIGATING THE EXTENT OF MICROPLASTICS POLLUTION IN GEORGIA'S COASTAL WATERS – AND THEY ARE ENCOURAGING PEOPLE LIKE YOU TO GET INVOLVED

WE CAN ALL MAKE A DIFFERENCE

It is a common misconception that plastics such as carrier bags or water bottles are only found at the ocean's surface. But, in a recent study, microplastics – tiny fragments of plastic measuring less than 5mm long – have been found 800 metres below the surface of the Pacific Ocean, and organisms are eating them. The Marianas Trench is the deepest part of the ocean —and pieces of plastic have even been found on the bottom there.

It is essential that we all reduce our usage of plastics, particularly single-use plastics. If every individual does their bit, their actions will have significant, positive environmental benefits.

The US National Oceanic and Atmospheric Administration (NOAA) defines microplastics as any type of plastic fragment that measures less than 5mm in length. Plastics have always been notorious for their damaging effect on the environment, not least because of how slowly they degrade, so improving understanding of microplastics pollution in the environment – particularly in aquatic and marine ecosystems – is essential. Given the small size of microplastics, they can be ingested by animals at the bottom of the marine food chain, causing unknown damage to the ecosystems they form part of.

Professor Jay Brandes is a marine chemist based at the University of Georgia's (UGA) Skidaway Institute of Oceanography, and his colleague Dodie Sanders is an environmental educator at the UGA Marine Extension (MAREX) and Georgia Sea Grant in the United States. They are working with a small team of researchers who are trying to ascertain the extent of microplastics pollution in Georgia's coastal waters. Georgia is a US state located in the South East and borders the Atlantic Ocean. Throughout the course of their studies, the scientists have found microplastics in almost every water sample they have taken on the Georgia coast and Jay believes the same or similar results would be seen worldwide. "It is clear from reading the studies published by other scientists that these contaminants are very widespread," he says. "Obviously concentrations vary tremendously by location, but where people have looked for microplastics, they generally have found them. It is very disconcerting."

HOW IS THE AMOUNT OF MICROPLASTICS IN WATER MEASURED?

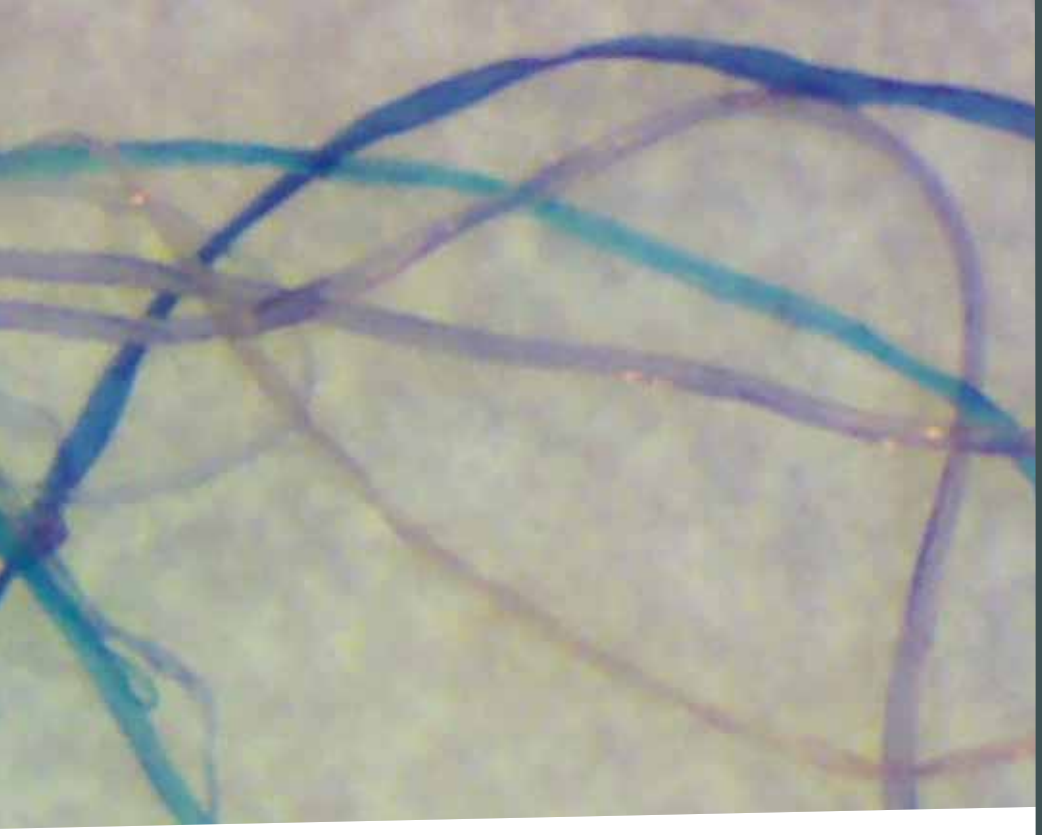
The UGA Skidaway/MAREX team do all their microplastics work visually, with a microscope. They collect water samples by going to a location, either by boat, or using a dock or a bridge, then use a stainless steel bucket to collect water, which they filter through a series of sieves. The researchers have to be very careful not to contaminate these samples with fibres and other plastics from their own clothes, so they stand downwind of the sample when filtering. They then rinse the sieves off and collect the particles into glass vials that have been carefully cleaned to eliminate contamination. Finally, they bring the vials to the lab, filter them onto another filter, and study this new filter under a microscope.

There are specialised microscopes that look at samples in different ways, such as with infrared light, that can tell you specifically what plastic type you have in your samples. While the team does not have one of these at the moment, they were recently told that a proposal to the National Science Foundation to purchase one of these instruments was approved for funding. So, they are very excited about the possibilities of making more informative studies of their samples in the near future.

HOW DO MICROPLASTICS GET INTO THE WATER SYSTEM?

There are a number of ways. One of the biggest is through the washing of clothing that is made up of plastics-based textiles. Take a look at your clothing labels next time you put them in a washing machine and see how many have polyethylene, spandex, rayon, nylon or other plastics as part of their make-up. Every time these materials are washed some of their plastic fibres detach and are washed away. Those fibres go down the drain, to the sewers, to the wastewater treatment plant and, because they are so tiny, often travel through the treatment plant and into the surrounding environment.

Plastic fibres and other bits of plastic can also shed from our clothing, rugs, food and drink containers, and other sources – and can travel a long way. A recent study found microscopic plastic fibres in the air in the European Alps, miles away from the nearest town. At first, scientists believed that microplastics were



mostly produced by the breakdown of larger pieces of plastic like cups and bags, but their widespread observations of fibres have changed this view somewhat. "We certainly thought that we would mostly see pieces of plastics and maybe microbeads from cosmetics in our samples when we started work in 2016," explains Jay. "However, we have mostly seen fibres!"

IS IT POSSIBLE TO REMOVE MICROPLASTICS ONCE THEY ARE IN THE WATER SYSTEM?

Removing microplastics is a very difficult task once they get out into the environment. While there are effective techniques to trap and remove them in waste-water treatment plants, use of these techniques is not universal nor all that common. Once out in the environment, there is the problem of trying to remove plastics that are the same size as organisms and detritus in the water. The UGA Skidaway/MAREX team filter them out to measure them, but it is impossible to do that with the entire estuary! Not only would it be hugely disruptive, but one would inevitably trap and remove the very organisms the team is trying to protect. Really, the only practical solution is to reduce the sources of plastics and microplastics to the environment and change what we do use to types that break down more easily once they are in the environment.

HOW CAN WE REDUCE THE AMOUNT OF MICROPLASTICS IN THE ENVIRONMENT?

On the one hand, with millions of tons of plastics entering the oceans each year, the problem seems hopeless. But people should keep in mind, the world has created this problem over decades, and it will take time to solve. A first step would be to reduce our usage of plastics, especially single-use plastics, in our every-day lives. This means always using reusable bags when shopping, avoiding buying plastic bottles for drinks, trying to avoid buying pre-made food packaged in plastic bags and containers. Packing a lunch in a lunchbox or paper bag can be cheaper than buying pre-packaged sandwiches, for example, as well as fun when choosing a variety of different things to eat.

Try to choose natural fibre textiles like cotton, linen and bamboo for your clothing and bedding. Recycling is problematic; much of it goes into landfills or is sent to developing countries where it may not be properly disposed of, so reducing your consumption of throwaway plastics is your best choice. Being educated on the issues is also important – often people do not understand why laws like banning disposable plastic bags are good reducing the amount of plastics that make it into the environment.

More importantly, it is vital to not get discouraged at the size of the problem and give up. Every action, no matter how small, helps. "I firmly believe that we will eventually have biodegradable plastics that are cheap and environmentally friendly as replacements for the throwaway, single-use ones we use today," says Jay. "People are working on this and have made excellent progress, but it will still take time."

JAY BRANDES

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

FIELD OF RESEARCH

Marine Chemistry

DODIE SANDERS

Environmental Educator
University of Georgia Marine Extension (MAREX) and Georgia Sea Grant, USA

RESEARCH PROJECT

Jay and Dodie are part of the UGA Skidaway/MAREX team that collects water samples to analyse the extent of microplastics pollution in Georgia's coastal waters.

FUNDERS

National Science Foundation, Georgia Sea Grant, the University of Georgia Foundation and private donations

ABOUT CITIZEN SCIENCE

Citizen science is where members of the public help conduct scientific research. This generally happens under the direction of professional scientists and scientific institutions, but this is not always the case. The power of collaborative research is often seen in fields where there are enormous data sets that cannot be managed by scientists alone, and computers are unsuitable for analysing the particular data.

Of course, given the amount of water on Earth, almost anybody – with the right training – can collect, process and analyse environmental microplastic samples. With this in mind, Dodie developed a citizen science programme that has become indispensable to the UGA Skidaway/MAREX research. "Our initial findings left us with many questions and avenues to explore, but how could we accomplish the work with our own small working group; and, how do we best engage, educate and inspire the public about marine pollution like microplastics?" she asks. "Our answer was to develop a microplastics citizen science monitoring programme along the coast to determine distribution and abundance of microplastics."

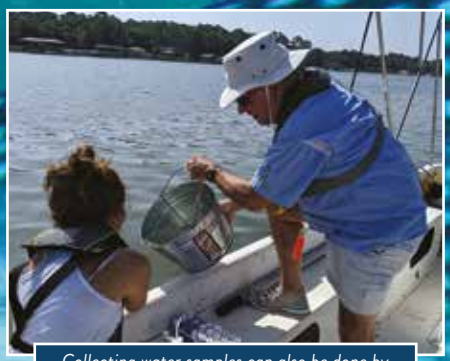
For a year now, Dodie has been working with several environmental groups, called Riverkeepers, in the Satilla, Ogeechee and Altamaha regions. These groups collect samples for microplastics analysis in the course of their regular sampling for other things such as nutrients and environmental toxins. Local citizen scientists round up their samples and bring them back to the research team for processing and analysis. She also has a group of volunteers from the UGA Marine Extension and Georgia Sea Grant who go out each week and collect samples from around the Georgia's coast, bring them to the lab, filter and count the microplastics in each sample, and report the data.

To do all of these activities using traditional academic models with technicians and graduate students would be very expensive, so the help that citizen scientists provide is invaluable for the Skidaway and UGA research, and science as a whole.

To find out more about how you can get involved in a citizen science project, take a look at The Big Microplastic Survey.

The research team collect samples from the water around Georgia's coast

Here, they are rinsing the sieves that contain water samples



Collecting water samples can also be done by citizen scientists like you

ASK PROF JAY BRANDES AND DODIE SANDERS

JAY, YOUR CAREER HAS ALWAYS BEEN CONCERNED WITH CHEMISTRY AND OCEANOGRAPHY. DID YOUR INTEREST IN THE OCEAN DEVELOP WHEN YOU WERE A CHILD?

I've wanted to be an oceanographer since I was about six years old. I kind of joke about it to my children, who have not had that kind of certainty about what they want to do in life, and are still trying to figure it out (my daughter is 17 and my son is 21). How I came to that conclusion is due to a combination of influences. One was the influence of 'The Undersea World of Jacques Cousteau' on TV when I was a kid. But I think the bigger influence was just visiting the sea in northern California where my grandparents lived and, later on, where I and my family lived. I loved being there, investigating tide pools and scuba diving in the kelp forests. The sea is a beautiful, magical place.

WHO OR WHAT INSPIRED YOU TO STUDY CHEMISTRY?

Very good teachers in college. I was lucky enough to live relatively close to one of the few universities at the time that had an undergraduate degree in oceanography (Humboldt State University, in Arcata, California). As part of the oceanography degree programme, students there had to take classes in the four main research areas in oceanography: biology, chemistry, geology and physics. Only then were you allowed to take more than just the introductory oceanography courses. I found that I enjoyed chemistry more than any of the other fields – much of this was because I was fortunate to have several great teachers in that field, who made their classes interesting. So, I think it was a combination of just being good at it and getting inspired to go into the subject.

DODIE, YOU ARE AN ENVIRONMENTAL EDUCATOR AND HAVE BEEN ENGAGING THE PUBLIC IN OCEANOGRAPHY RESEARCH FOR 30 YEARS. WHY ARE YOU SO PASSIONATE ABOUT CITIZEN SCIENCE?

Citizen science programmes are beneficial to research groups, monitoring agencies and policymakers, and can positively impact communities as citizen scientists become informed and empowered. Microplastics research is a relatively new science, which has caught the interest of the public, and this has led to individuals and environmentally-focused groups wanting to volunteer their time to help. Engaging these citizen scientists creates "force multipliers", meaning greater distances can be covered in shorter timescales. Not only that, but also as citizen scientists become more knowledgeable, their understanding will influence larger decisions about science policy.

DO YOU WORRY ABOUT THE HEALTH OF OUR OCEANS?

Jay and Dodie – Very much so. The oceans are under threat from the changes humans are making. Aside from plastics and microplastics, there are huge problems with overfishing, coral bleaching, acidification, temperature changes, the rise of sea levels, pollution, and so on. The ocean seems endless, but it is being stressed by the impact of so many people and their activities. Coral bleaching has already heavily damaged coral reefs around the world. Future generations will be denied seeing these places in their glory. What do we tell our children when they look at the old photos and movies of these places and ask, what happened?

JAY AND DODIE'S TOP TIPS

01 Know yourself! If working on science that involves both chemistry and the sea is your passion, then great! If you find chemistry boring but love the sea, that isn't enough. Being a successful marine chemist requires both having a passion for it and aptitude for it. There are lots of long hours and frustrating research difficulties to overcome, so you need the drive to keep going!

02 Make sure you get a good background in chemistry as an undergraduate – most of the student applicants we see for our graduate programme do not have a degree in marine science or oceanography. That is ok, if they are good at their chosen specialty.

03 If at all possible, try getting a summer internship at a marine lab or other place that does ocean-related research. This will really help you decide if this is the field for you, will make your graduate school applications stand out, and give you experience in how science is done in this field.

04 Write and write and write! People often neglect the skill and importance of writing. No matter the job, one is constantly evaluated on how proficiently they write – developing strong writing skills and habits will take you a long way.

MARINE GEOSCIENCE: JUST A DROP IN THE OCEAN

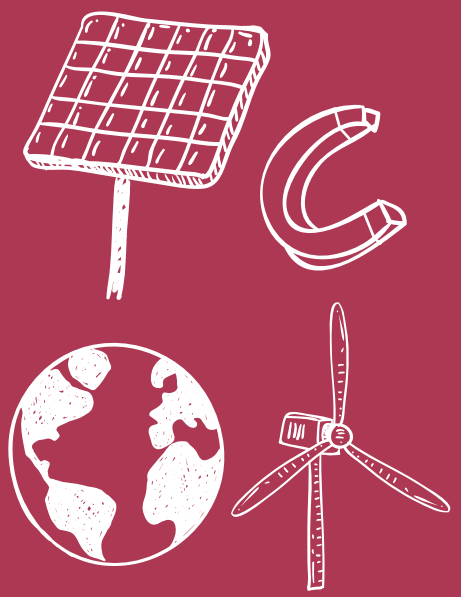
PROFESSOR BRAM MURTON IS THE ASSOCIATE HEAD OF MARINE GEOSCIENCE AT THE **NATIONAL OCEANOGRAPHY CENTRE** IN THE UK. HIS RESEARCH COVERS MANY AREAS, INCLUDING THE DEEP OCEAN MINING OF MATERIALS SUCH AS TELLURIUM, WHICH CAN BE USED TO PRODUCE RENEWABLE ENERGY TECHNOLOGIES

IMAGINE THIS

You don't have to go into space to be the first human being ever to explore an area: 70% of our planet is covered by water and yet only 2% has been explored.

With the help of submarine robots, Bram and his team are finding new ways to mine for minerals and metals under the sea. These materials can be used to build solar panels, rechargeable batteries (for electric cars) and magnets needed for wind turbines.

Could deep sea mining be the solution we need to reduce our reliance on carbon-based fossil fuels?



Our planet is an extremely vast place with an apparent abundance of riches. However, as the global population continues to grow rapidly, the demand for materials is outstripping our ability to recycle existing sources and replace what has been used. In addition, the burning of carbon-based fossil fuels has damaged Earth and significantly contributed to global warming and climate change. For these reasons, it is important for us to find new minerals and metals, particularly those that are essential to building low-carbon technologies.

One exciting, and surprisingly underutilised, potential source of new minerals and metals is the seas and oceans. Seventy percent of the Earth's surface is covered by water and the deep seafloor contains mineral deposits in the form of manganese and iron-rich nodules, cobalt-rich crusts and massive sulphides.

It is these cobalt-rich crusts that are the focus of Professor Bram Murton's research. As the Associate Head of Marine Geoscience at the National Oceanography Centre, in the UK. Bram leads a team of scientists who are interested in cobalt, tellurium and rare earth elements.

WHAT ARE THESE ELEMENTS USED FOR?

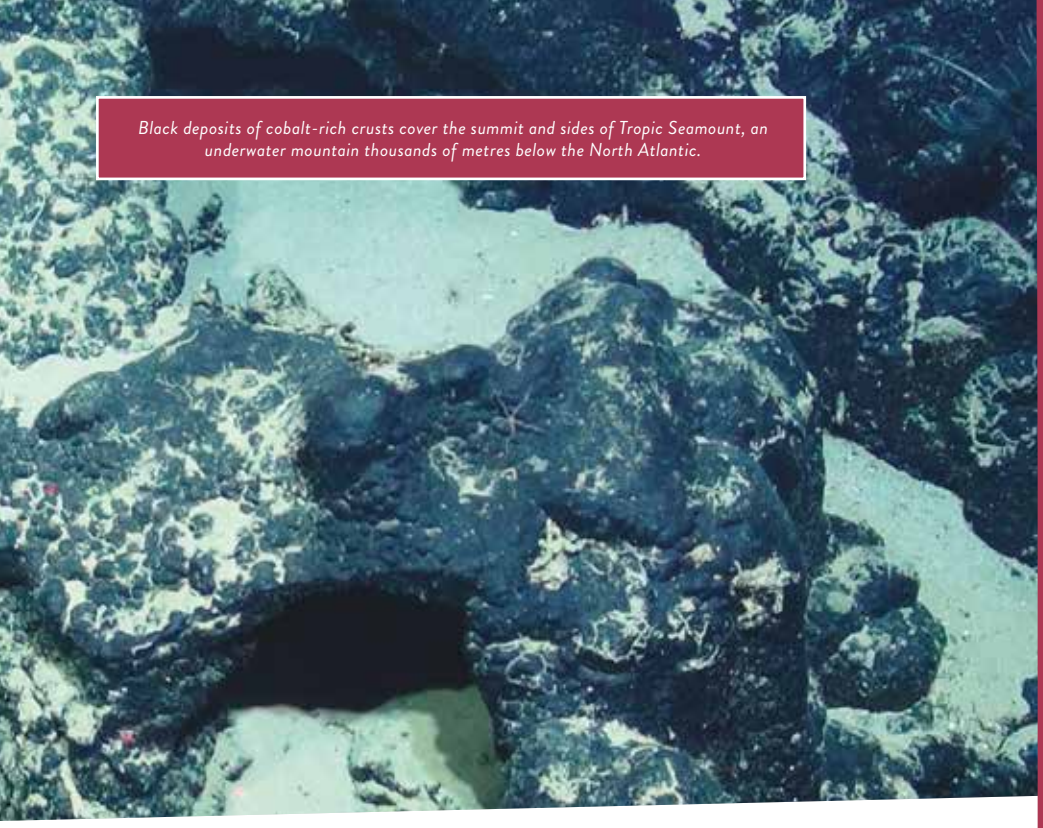
Cobalt is used in many materials, from special alloys in aircraft to machine tools, and more recently in rechargeable batteries. At the moment, 70% (90,000 tonnes per year) of cobalt comes from the Democratic Republic of Congo, a war-torn country in central Africa. Cobalt is not mined directly but is a by-product of copper production. In the future, demand for cobalt will be driven by electric cars.

Tellurium is a very rare element, even rarer than gold. Its traditional uses are for lead-acid batteries, as a pigment in ceramics (needed to create beautiful colours), and as a catalyst in hydrocarbon refining (an industrial process where crude oil is transformed into useful products such as petrol). Bram's interest in tellurium is in its use for improving the efficiency of solar panels to convert sunlight into electricity.

There are 15 rare earth elements listed in the lathanide series (a group of elements in the periodic table) and, in spite of their group name, are not particularly rare – especially when compared with tellurium. But they have special properties that make them in high demand. For example, the heavy rare earth elements neodynium and praseodymium are used in strong electric magnets that are essential for electric motors and wind turbines. Rare earth elements are also used as catalysts in chemical reactions, in mobile phones and computer memory.

HOW AND WHY DO RESEARCHERS MINE UNDER THE SEA?

The grade of the metals is higher for many elements in seafloor minerals than on land. That means less rock has to be removed to get the same amount of metal. Then there is the fact that seafloor mines do not need infrastructure like roads, railways, or the relocation of people from their homes.



Black deposits of cobalt-rich crusts cover the summit and sides of Tropic Seamount, an underwater mountain thousands of metres below the North Atlantic.

However, there are technological challenges to deep-sea mining: exploring for the ore deposits, assessing their value and grade, extracting the ore from the seabed, lifting it thousands of metres to the surface, weathering storms, and shipping the ore to shore. Deep-sea mining has only been done in small scale trials so far, but the technology is advancing fast and it is only a matter of time before large commercial-scale operations are underway.

WHAT ARE THE MAIN CHALLENGES OR HURDLES IN THIS FIELD OF RESEARCH AT THE MOMENT?

The bottom of the ocean is a hostile and extreme environment. "There is no light, the ocean floor is full of corrosive seawater under high pressure, and it is very remote. Navigation is difficult – there is no GPS, no radio signals and no landmarks," explains Bram. "We have to use sound to navigate. Seeing is very difficult – we can only see for 20 metres or so and we have to use echosounders to build a picture of what is there." Bram's team spends five or six weeks each year on a ship in the middle of the ocean, deploying robot submarines, collecting samples and analysing rocks. These data and samples are bought back to Bram's lab where the research group continue with more sophisticated analyses.

Another important consideration is to reduce the environmental impacts of mining for these materials. One of the more important environmental impacts of deep-sea mining is the effect of plumes of water that carry dust and sediment away from the mined area into other areas of the seafloor. So, Bram's team has conducted experiments to study the effects of the sediment plumes, both on the seafloor and on the sea surface.

Their results so far show that the plumes settle much quicker than previously thought and the chemicals are not as poisonous as believed. This allows people in the future to better design the mining plans to minimise any environmental damage.

PROFESSOR BRAM MURTON

Associate Head of Marine Geoscience
National Oceanography
Centre, UK

FIELD OF RESEARCH

Marine Geoscience

RESEARCH PROJECT

Bram's work focuses on deep ocean mining of minerals and metals. His interests are varied, but one key project involves attempting to address problems associated with the burning of carbon-based fossil fuels. As such, his team are investigating cobalt-rich crusts to find cobalt, tellurium and rare earth elements, all of which are critical to building low-carbon technologies.

FUNDERS

Natural Environment Research Council and UKRI

You can read more about what Bram's team has been doing at sea on their blog: Marine E-tech Research Expedition.

The arm of a robotic submarine breaks off a piece of cobalt-rich crust for later analysis.

ABOUT MARINE GEOSCIENCE

Marine geoscience is a form of planetary science which involves studying the Earth. Seventy percent of our planet is covered by ocean and, similar to space exploration, there is so much that we still do not understand. Marine geoscientists aim to fill in these knowledge gaps using a wide range of tools and methods. Both robotic and manned vehicles are used to explore the deep-ocean floor down to 6,500 metres below the sea surface. It is possible to explore even deeper – down to 11,000 metres, the deepest places on Earth!

WHAT IS IT LIKE TO BE A GEOSCIENTIST?

Being a marine geoscientist is extremely exciting as you have to be an expert in lots of different areas: technology (sometimes designing your own vehicles and machines), geology (to understand the formation of the rocks and minerals), geophysics (to understand the remote sensed data and sonars), geochemistry (to analyse the rocks in the lab), a mariner that is happy to go to sea on expeditions for weeks at a time, and an enthusiast for the unknown (only 2% of the world's oceans have been explored – so wherever you go, you are nearly always the first human being to see it and explore it).

WHAT CAREER OPPORTUNITIES ARE AVAILABLE WITH A DEGREE IN MARINE GEOSCIENCE?

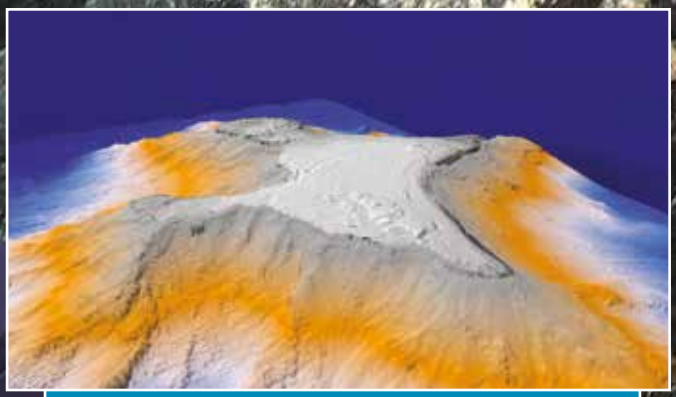
Careers in marine geoscience research are hard to get, but far from impossible. If you follow your dreams and have a little bit of luck, then a career in this field could be within your grasp. Other related career opportunities are on the rise: offshore surveying is growing fast with the drive for renewable energy from offshore wind and wave, or oil and gas – and this requires marine geophysicists; marine-protected areas require surveyors to monitor for changes; cables cross the oceans and require marine geoscientists to survey where to lay them; and in the near future, deep-sea mining will require deep-sea mineral exploration.

WHY SHOULD YOUNG PEOPLE WANT TO STUDY MARINE GEOSCIENCE?

For many reasons! Geoscience is an adventure and has the power to make a huge difference to people and humankind – from understanding the history of climate change, to providing resources and materials from which we can build a sustainable future civilisation. It is varied, and never boring.

OPPORTUNITIES IN GEOSCIENCE

- The British Geological Survey has an entire area of its website dedicated to training within the field of geoscience: www.bgs.ac.uk/training/home.html
- The Geological Society says that a starting salary for a geoscientist can vary anywhere between £28,000 and £35,000, with senior geoscientists earning between £40,000 and £75,000 per year
- The Geological Society has also created a wonderful Geology Career pathways webpage, which allows you to explore your career pathway by clicking on animated characters. Have a go and see where a geology career could take you! www.geolsoc.org.uk/Geology-Career-Pathways



Multibeam sonars from the surface ship and deep-diving robotic submarines map the shape of Tropic Seamount, which is 40 km wide and between 1 and 4 km deep.

At 50 parts per million, cobalt-rich crusts are 50,000 times richer in tellurium, a very scarce element used in photovoltaic solar panels, than continental crusts!

ASK PROF BRAM MURTON

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

I was interested in everything technical, scientific and to do with space. We lived in the west coast of Scotland and I remember trying to build an underwater lab from an old large metal water tank. Luckily it floated away! My heroes were the *Tomorrow's World* presenters. However, it would be untrue to say that I dreamt of being a scientist or that I plotted a path to be a professor at an early age. I followed my curiosity and developed my interests in our natural world, and the rest came from serendipity and blind enthusiasm.

WHAT MADE YOU WANT TO STUDY GEOLOGY AND MARINE GEOSCIENCES?

As a kid, I was once taken on a gold-panning trip by a famous Antarctic explorer and geologist who was on holiday in my village. I asked lots of questions about the mountains, the minerals we could see, and how the Earth formed. The answers were fascinating, and I longed to understand how an apparently unique planet like the Earth was formed. After tossing a coin to choose between studying geology and geophysics at Edinburgh University (geology won), I went on to do a PhD at the Open University under the supervision of Professor Ian Gass FRS, researching the Troodos Ophiolite – an uplifted fragment of 90 million-year-old oceanic crust that now forms the mountains of Cyprus.

Fascinating as this was, I became increasingly aware that the 70% of Earth covered by the ocean is almost unknown, and I wanted to find out more about plate tectonics in action. I was invited on an oceanographic research cruise mapping the seafloor in the West Pacific with new sonar systems. Being the first to see the seafloor in this region, and the first to see new volcanoes and faults, got me hooked.

YOUR RESEARCH FOCUSES ON FINDING MATERIALS THAT ARE USED MAINLY FOR LOW CARBON AND RENEWABLE ENERGY TECHNOLOGIES (SOLAR PHOTOVOLTAIC, WIND TURBINES AND ELECTRIC VEHICLES). ARE YOU AN ECO-WARRIOR?

I am not a warrior of any kind – except maybe for the rational truth. But I am deeply concerned about the planet; it's our only one and will always be unique for us. I am concerned that people are consuming it without regard for the future. I want people to have a happy and healthy life, without destroying everything around us. This leads us to a dilemma: to become more sustainable, people must recycle and use more renewable energy, but there aren't enough of those materials to make this happen. So, we need more raw materials. This sounds contradictory, to reduce consumption we need to consume more, but it is about consuming the right sort of materials that ultimately enable us to consume less. Deep-sea mining has a lot of potential advantages over land-based mining. To realise the full potential, we need to find out a lot more about the nature of the mineral deposits, where they form and are most concentrated, and the effects of mining them. I am motivated by helping people to have a sustainable future, reducing poverty and preserving our planet.

FINALLY, WHAT DO YOU LOVE MOST ABOUT YOUR JOB?

My job has given me the opportunity to discover things, to explore places and to see things no one has ever seen before. Its variety and opportunity have been amazing. I have built machines that have discovered the deepest and hottest hydrothermal vents on Earth. I have dived in a mini-submarine 3,500 metres below the surface to discover new forms of life. I have built teams and made new friends around the world, from multiple different cultures, all enthusiastic about discovery. My work, I hope, will ultimately help solve some of the world's problems. I have been given the chance to make a difference for the better.

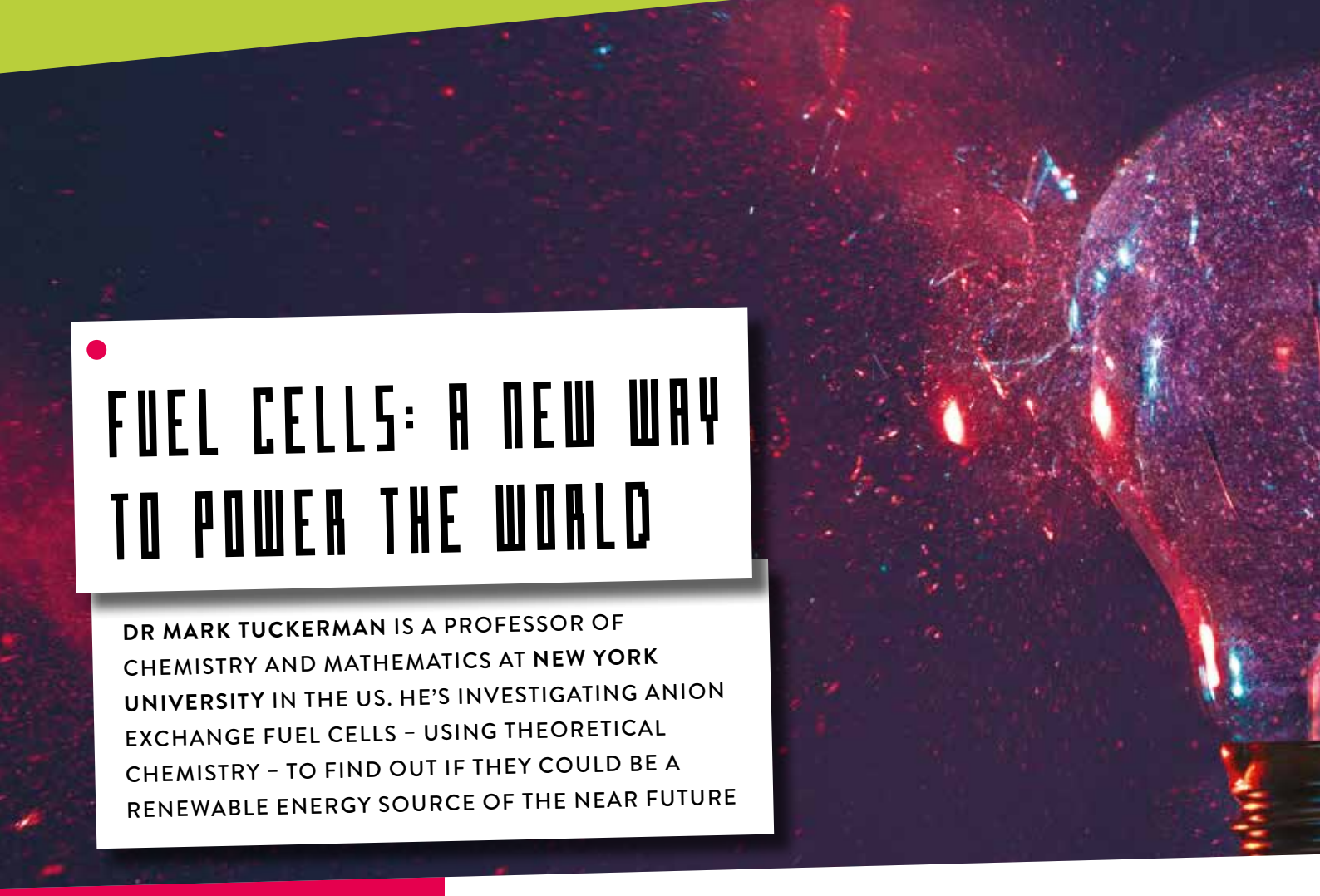
BRAM'S TOP TIPS FOR STUDENTS

01 One of the most important things to remember is that scientists are just like everybody else. It is perfectly normal to be enthusiastic, interested, questioning and unsure of one's self. Keep this in mind at all times.

02 Marine geoscience requires a wide range of skills. A grounding in chemistry and physics at A level is a good start. Plus, a wider range of skills including team work, independent and critical thinking, self-reliability and sociability are essential.

03 If you get the chance, meet people in the business, go to trade shows and talk with people from the industry and local geological society – and attend talks! They are often by experts in the field and can be inspiring.

If all the tellurium in the cobalt-rich crusts was used to make solar panels, they could provide two-thirds of the UK's electricity supply on a sunny day.



FUEL CELLS: A NEW WAY TO POWER THE WORLD

DR MARK TUCKERMAN IS A PROFESSOR OF CHEMISTRY AND MATHEMATICS AT **NEW YORK UNIVERSITY** IN THE US. HE'S INVESTIGATING ANION EXCHANGE FUEL CELLS – USING THEORETICAL CHEMISTRY – TO FIND OUT IF THEY COULD BE A RENEWABLE ENERGY SOURCE OF THE NEAR FUTURE

IMAGINE THIS

Anion exchange fuel cells offer us an opportunity to power the world in a way that does not emit greenhouse gases and contribute to global warming. Because these fuel cells can be powered with hydrogen fuel, the only waste products they generate are water and heat.

The design of anion exchange membrane polymer materials, a critical component of the fuel cell, involves an enormously large set of parameters, so theoretical chemists use computer simulations to narrow down the possibilities and arrive at guiding design principles. The findings are passed on to synthetic chemists who then have a more manageable number of polymers to make and test.

Ultimately, the findings could lead to new fuel cell designs capable of revolutionising how we power our world.

Global warming is something we have all become increasingly aware of over the past few years. It is known that the main cause of global warming is the production of greenhouse gases, such as carbon dioxide. These gases trap heat radiating from Earth to space, leading to a warming of the lower atmosphere and surface of our planet. The burning of fossil fuels is one of the leading causes of greenhouse gas production; hence scientists are working to develop renewable energy technologies that will reduce – or remove – the need to burn fossil fuels.

Currently, the way we power cars, trucks and other vehicles is reliant on the burning of fossil fuels, so attention has shifted to other energy sources such as batteries and electrochemical fuel cells. Dr Mark Tuckerman, Professor of Chemistry and Mathematics at New York University, leads a team that is particularly interested in anion exchange membrane fuel cells.

WHAT ARE ELECTROCHEMICAL FUEL CELLS?

A fuel cell is an electrochemical device capable of delivering power by converting the chemical energy stored in a fuel into electricity. Common fuel sources that are used include methanol and hydrogen. When methanol is used, the fuel cells produce carbon dioxide, which is undesirable; in contrast, when hydrogen fuel is used, the only waste products are water – which can be recycled back into the fuel cell – and heat. Hydrogen is difficult to produce efficiently, but a number of research groups are making new inroads into this problem.

Fuel cells can be used to power anything that runs on electricity, so they are ideal for common devices such as computers and mobile phones. They can also be used to power vehicles, where efficiencies reach 40-60% compared to the approximately 20% efficiency of typical petrol-powered engines. The heat generated by fuel cells can also be used to heat up homes, large apartment complexes, or office buildings and factories.

WHAT IS THE ADVANTAGE OF THE ANION EXCHANGE MEMBRANE FUEL CELL OVER OTHER ELECTROCHEMICAL FUEL CELLS?

In order to convert the chemical energy of the fuel into electricity, a fuel cell uses a pair of chemical reactions known as reduction-oxidation or "redox" reactions. Under normal conditions, these reactions can be quite slow, which makes the energy conversion process inefficient. In order to accelerate the chemical reactions, a catalyst is needed. "Platinum has proved to be an effective catalyst for redox reactions," says Mark. "Its use in the acidic conditions in which many fuel cells operate is

DR MARK TUCKERMAN

Professor of Chemistry and Mathematics
New York University, USA

FIELD OF RESEARCH

Theoretical Chemistry

RESEARCH PROJECT

Mark's research is focused on exploring the potential of anion exchange membrane fuel cells as a renewable energy technology. One of the chief aims of his work is to arrive at a set of fundamental design principles that can be used to generate a variety of anion exchange membranes exhibiting high hydroxide conductivity. Achieving this goal could ultimately result in high-performing hydrogen fuel cells with the potential to revolutionise how the world powers a wide variety of vehicles and instruments.

FUNDER

National Science Foundation
(Division of Materials Research)

preferred because it is particularly unreactive and less susceptible to corrosion under these conditions."

Alkaline fuel cells operate under basic conditions using a different set of redox reactions, which are their key advantage. Although a catalyst is still required, these operating conditions allow for catalysts to be constructed from cheaper metals, making the alkaline fuel cell a better candidate for mass production.

HOW DO ANION EXCHANGE FUEL CELLS WORK?

The basic operation of an anion exchange fuel cell is relatively simple. As with any electrochemical device, an anion exchange fuel cell consists of two metal electrodes, a positively charged anode and a negatively charged cathode, and an ion-conducting material between them known as an electrolyte. The two electrodes are also joined by an electrical circuit through which electrons produced in a chemical reaction at the anode flow to produce an electric current, driven by a voltage applied across the circuit.

At the cathode, oxygen is combined with water and the electrons to produce hydroxide ions. These ions are then transported through a hydrated polymeric material known as an anion exchange membrane (AEM), which serves as the aforementioned electrolyte material, to the anode. If the fuel cell is fed with hydrogen fuel at the anode, these hydrogen molecules combine with the hydroxide ions that arrive there to produce water and the electrons that produce the electrical current. (See diagram on page 3).

HOW IS COMPUTER MODELLING HELPFUL FOR IMPROVING AND MODIFYING THESE FUEL CELLS?

The key to the successful operation of an alkaline fuel cell is the creation of AEMs that can transport the hydroxide ions as efficiently as possible. Experimentally making and testing all the possible AEMs is both wasteful and extremely time consuming. By using a computational model, however, Mark and his team can explore a large space of AEM design parameters simply by tweaking a few numbers and repeating calculations – a considerably easier task. Therefore, computational investigation of the performance of different possible AEMs allows the parameter space to be narrowed down to a few key values that can be passed on to synthetic chemists. This means that synthetic chemists have a much smaller set of polymers to make and test, and the resulting hydrogen fuel cells could go to market much more quickly.

Mark explains: "To give you an idea of what can be investigated computationally, we can predict the morphology [form or structure] of a given polymer architecture, estimate the rate of hydroxide transport, and study the chemical stability of the material in the presence of the alkaline solution in which it is immersed." These predictions can be tested against experimental results, which then help to refine the computational models. The improved models, in turn, become better guides for the synthesis, and so on. This type of feedback loop can be a powerful route to the rapid design of new functional materials such as AEMs and to the discovery of general optimal design principles for these materials.

WHAT IS THEORETICAL CHEMISTRY?

From an eagle-eye view, theoretical science exists to give a higher sense of order to experimental observations as they are presently known, or to point to new observations that can be experimentally verified. Without theory, experimental science is merely a catalogue of measured results. More specifically, to understand what theoretical chemistry is, it is important to position it within the wider context of chemistry as a whole. Because chemistry is, in essence, the science of molecules, their interactions and transformations – and molecules are nothing more than assemblies of atoms whose behaviour is governed by the fundamental laws of physics – it is possible to approach chemical problems from a theoretical physical perspective.

Thus, theoretical chemistry applies the basic equations of physics to atomic assemblies to reveal how atoms arrange to form molecular structures and how they move in chemical reactions to cause molecular transformations. Such atomic level information can provide insights into chemical processes that cannot be accessed experimentally. As these equations are enormously complicated, obtaining analytical, mathematical solutions is generally not possible, which is why high-performance computers and sophisticated algorithms must be used.

WHAT BENEFITS DOES THEORETICAL CHEMISTRY BRING TO SOCIETY?

The synergy that exists between theory and experiment means that the resources and amount of time needed to solve a particular problem can be reduced. Theoretical chemistry is now an integral and indispensable part of chemical research and plays a major role in bringing the benefits of scientific research to society as a whole, including areas such as medicine, clean energy, electronics and advanced materials.

WHY SHOULD YOUNG PEOPLE STUDY THEORETICAL CHEMISTRY?

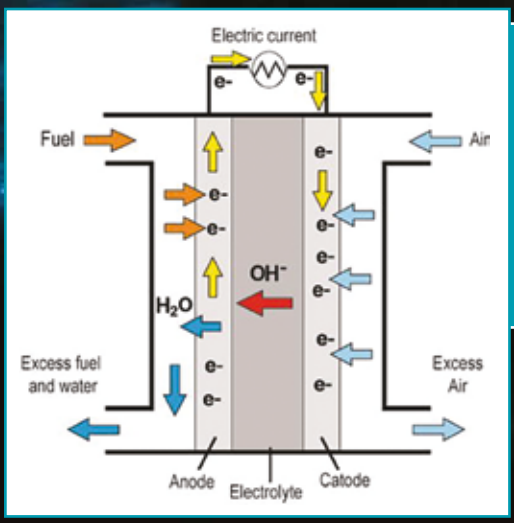
Theoretical chemistry trains students in skills that are applicable in both academia and industry, and that are transferable beyond the molecular sciences to an increasingly technically-orientated job market. In order to work in theoretical chemistry, students need to be familiar with advanced mathematical methods and statistics, be skilled in programming and software design and, depending on their particular research area, have a good understanding of biology, physics, computer science or engineering, and, of course, chemistry.

IF A STUDENT IS INTERESTED IN A CAREER IN THEORETICAL CHEMISTRY, WHERE WOULD BE THE BEST PLACE TO START?

A career in theoretical chemistry requires an advanced university degree in the subject, meaning, at the very least, a Master's degree or, far better, a PhD. Therefore, gaining admission to a graduate programme is essential. Generally, the best undergraduate degrees from which to springboard into a graduate programme in theoretical chemistry are physics, chemistry, chemical engineering, applied mathematics or biology.

WHAT OPPORTUNITIES ARE AVAILABLE FOR THEORETICAL CHEMISTS?

Academic research is not the only career path for someone with an advanced degree in theoretical chemistry. Computational chemists are needed at pharmaceutical and chemical companies and are also highly sought after in scientific software developments companies. As mentioned above, the skills learned by theoretical chemists are highly transferable to non-scientific fields, including finance, data science, research administration and science policy.



The basic operation of an anion exchange fuel cell is relatively simple.

Source: S. Castañeda Ramírez and R. Ribandeneira Paz in New Trends in Ion Exchange Studies, InTech Open Series (DOI:10.5772/intechopen.77148), 2018.

OPPORTUNITIES IN THEORETICAL CHEMISTRY

- The American Chemical Society says that the median salary for theoretical chemists is $100,000.
- There are a wide range of paid positions for students seeking summer internship opportunities. You can work closely with a senior scientist to boost your skills and knowledge.
- Internetchemistry.com provides lots of resources on computational and theoretical chemistry, including software, lecture notes and tutorials.

ASK DR MARK TUCKERMAN

WHO INSPIRED YOU TO STUDY THE SCIENCES WHEN YOU WERE AT SCHOOL?

While I learned science from many truly excellent professors during my undergraduate years, I was largely inspired by an abstract admiration for the giants of physics – Einstein, Feynman, Bohr, Schrödinger, Heisenberg, etc. – and a desire to understand, both conceptually and mathematically, what they had achieved.

YOUR UNDERGRADUATE DEGREE AND PHD ARE IN PHYSICS, YET YOU ARE A PROFESSOR OF CHEMISTRY AND MATHEMATICS, AND MUCH OF YOUR RESEARCH INVOLVES COMPUTER MODELLING. WHY DID YOU CHANGE FIELDS?

As an undergraduate physics major, I was doing research in theoretical particle physics. While I thoroughly enjoyed this type of abstract, highly mathematical research (and still do), I maintained a strong tangential interest in molecular science, perhaps because it was easier to see its broad and immediate applications. When I got to graduate school, I waivered a bit between these two areas, but when I came to realise just how many of the things I had learned in my study of theoretical physics were also applicable in theoretical and computational chemistry, the choice became much clearer. It was actually possible for me to work with the abstract methods I had learned as a theoretical physicist and apply them in an area that seemed imminently practical!

DID THIS CHANGE IN FIELDS REQUIRE A LOT OF RE-TRAINING AND LEARNING?

I suppose there was a learning curve to ascend in changing fields, shoring up the gaps in my chemistry knowledge, and re-training my mind to look at things in the way chemists do. I was surprised at how much of a language barrier there was, at that time, between the physics and chemistry communities, which required me to learn a new vocabulary. However, I pushed myself to quickly become conversant in this vocabulary because I knew that, as a newly minted assistant professor of chemistry, I would need it to do something I had never done before – teach undergraduate chemistry courses!

In terms of my research, which has a significant overlap with physics, there was not such a chasm to bridge; indeed, the gap between physics and chemistry has narrowed further over the years since I made the transition. However, I am ultimately glad that I started out in physics because the training it provided ultimately proved invaluable for my work in theoretical chemistry. Moreover, I suspect it is easier to make the switch from physics to chemistry than it would be to do the reverse.

FINALLY, WHAT IS THE MOST ENJOYABLE PART OF YOUR JOB?

It's very difficult to say – it's like asking: "What is your favourite part of a chocolate sundae or a tiramisu?" Imagine a career in which you have complete freedom to work on whatever interests you and experience the thrill of discovery as part of your job description, and you'll have a good idea of what being an academic researcher is like. This might well be the best job there is, even if it isn't that remunerative financially. Every day is different and stimulating in some way.

There are opportunities to travel and have stimulating discussions with colleagues all over the world. Best of all is the opportunity this job affords to shape the next generation of scientists. Seeing one's students and postdocs mature as researchers, watching them come up with their own ideas, and witnessing their thrill of discovery when their ideas finally work – of all that this job entails, this aspect may be the most rewarding!

MARK'S TOP TIPS FOR STUDENTS

01 Earning an advanced degree in theoretical chemistry requires hard work and commitment. If you wish to gain a PhD, it will probably take between five and six years beyond your undergraduate degree. While it can be frustrating and humbling, ultimately it will prove very rewarding.

02 If you are majoring in chemistry, be sure to enrol in mathematics and physics courses beyond those that are required. Courses to choose include multivariable calculus, linear algebra, differential equations, classical and quantum mechanics, and statistical mechanics.

03 It will also be highly beneficial to learn one (or more) programming languages. Particularly useful choices are Python and C++. Do try and get involved in undergraduate research, too – the practical training and perspective on research you will gain from the experience will be invaluable.

"DON'T LET YOUR CIRCUMSTANCES DICTATE YOUR FUTURE"

IMAGINE WORKING YOUR WAY UP FROM A BROKEN HOME TO A PLUSH JOB AT SALESFORCE; OR EXPERIENCING DOMESTIC VIOLENCE AND BECOMING A RESEARCHER IN A TOP-FLIGHT UNIVERSITY; OR LIVING IN FOSTER CARE AND DESIGNING AN AWARD-WINNING MENTAL HEALTH APP. DOINA ONCEL HAS OVERCOME HUGE CHALLENGES TO BECOME FOUNDER AND CEO OF hEr VOLUTION, AND SHE'S ON A MISSION TO HELP GIRLS AND YOUNG WOMEN FROM DIVERSE BACKGROUNDS SEE THEIR FUTURE IN STEM

WHY DID YOU SET UP hEr VOLUTION?

I come from a social work background and have worked with people from underserved communities, in particular, in Toronto in Canada. I've also needed to access homelessness, domestic violence, poverty and immigration services. When I learned about the lack of women in STEM, it made perfect sense to me that there should be an organisation that brings diversity to the sector – people who would love to access opportunities in STEM but face multiple barriers, or who aren't even aware that these opportunities exist. In Canada, the STEM sector is not diverse. People with money or from more elite backgrounds tend to work in STEM so, at hEr VOLUTION, we aim to change that.

hEr VOLUTION SUPPORTS WOMEN FROM UNDERSERVED COMMUNITIES, IN PARTICULAR. WHAT KINDS OF BARRIERS DO THESE WOMEN HAVE TO OVERCOME?

Some of the barriers that women from the underserved community face are: not having enough money to pay for education; not having an income for their kids; not being aware of opportunities or the skills needed for the future. We've discovered that the skills required in the next 10-15 years, in order to get a job, are in STEM. A lot of the people from underserved communities aren't equipped for any form of employment, and so they'll continue to be underserved.

WHY ARE YOU ENCOURAGING YOUNG WOMEN TO STUDY AND FOLLOW CAREERS IN STEM?

STEM careers are better paid, the careers of the future are STEM-based and if we want to prepare women for the future, then we have to look to STEM. Let me use my eldest daughter as an example. She's 16 and she's really good at art. She wants to be an illustrator or animator and she's looking at colleges and universities. Illustration and animation might be her passion, but I tell her to think beyond that. If she has a computer science degree, she can take animation and illustration to the next level. She'll have more opportunities open to her than with a degree in animation – even as an animator – because anything she works on will require her to use a computer. If you want a solid career it's always a good idea to be ahead of the game.

ABOUT DOINA ONCEL

Doina faced multiple barriers during her lifetime, including domestic violence and homelessness. A single mother of two daughters, she now heads hEr VOLUTION, an organisation that aims to revolutionise the STEM industry.

ABOUT hEr VOLUTION

Based in Toronto, Canada, hEr VOLUTION provides opportunities for young women, especially those from underserved communities, to access careers in STEM (science, tech, engineering and maths) through workshops, seminars, education and career programmes, conferences and events.

www.hervolution.org

WHAT RESOURCES DO YOU OFFER GIRLS AND YOUNG WOMEN?

We organise educational programmes and events. For example, we have a high school computer science programme and other similar programmes focusing on space science, tech, coding, engineering, etc.

Just under half of our attendees at our end-of-year conference are high school and post-secondary students. Our STEM conferences are different to other STEM conferences in that we talk about challenges and how to overcome those challenges. We also connect young women with STEM opportunities and mentorships.

WHAT AGE GROUP ARE YOU TARGETING?

Our programmes are aimed at girls in grade 1 to grade 12. A lot of statistics suggest that by the time they reach 12 years old, they will have already decided whether or not STEM is for them. We want to show them that STEM isn't just for nerds, which is why we have a webpage dedicated to Canadian women in STEM. These women act as STEM role models and mentors for young women.

ARE THESE RESOURCES OPEN TO ALL GIRLS AND WOMEN WORLDWIDE?

At the moment we serve Ontario, but we're working on serving the whole of Canada. We've been in existence for six years and we're in the process of creating a solid foundation and understanding of the barriers before multiplying our programmes across the country.

We also offer volunteering opportunities to women outside of Canada so that they can get the experience they need to live in Canada. This experience doesn't necessarily have to be in STEM; we offer experience in marketing, PR, whatever, and we've had graphic designers from Netherlands, Australia and India.

WHAT DOES "UNDERSERVED" MEAN?

WOMEN FROM "UNDERSERVED COMMUNITIES" ARE UNABLE TO ACCESS VITAL SERVICES, FROM HEALTHCARE TO THE INTERNET.

> *STEM careers are better paid, the careers of the future are STEM-based and if we want to prepare women for the future, then we have to look to STEM.*

YOU WORK WITH A LOT OF PARTNERS, INCLUDING SHOPIFY, SALESFORCE, THE SOCIETY OF WOMEN ENGINEERS.... IN WHAT WAY DO THESE PARTNERS WORK WITH YOU?

One way to get young women excited about STEM is to give them first-hand experience in a company. For example, Salesforce or Shopify offer young women exposure to work experience, which means they really get to see what it's like to work there. We started this idea a couple of years ago and we've found that a lot more women pursue STEM careers in this way than when we only give talks or presentations.

ON YOUR WEBSITE, YOU ARE DESCRIBED AS AN IMMIGRANT WHO HAS EXPERIENCED HOMELESSNESS, DOMESTIC VIOLENCE AND MANY OTHER DIFFICULT CIRCUMSTANCES. WHO OR WHAT CHANGED YOUR CIRCUMSTANCES TO ALLOW YOU TO BECOME THE INSPIRATIONAL PERSON YOU ARE TODAY?

When people call me inspirational, I always think, why, what have I done?! Yes, I was an immigrant with no resources, no social network and a low income. I was 19 when I moved to Canada from Romania and I couldn't speak the language. I had to go to shelters quite a few times, I slept on people's floors – it was tough. I also have two daughters who are a huge inspiration for me.

To be honest, my eldest daughter was only 7 years old when I was last in a shelter and experienced violence. At that time, she said to me: "When I grow up, I want to be just like you." I thought to myself, what am I showing her? If I become a better person then she'll aspire to become a better person, but if I stay here, in my victim zone, she's never going to aspire to anything more, so I decided I needed to lead by example. That was a huge turning point for me.

WHAT MESSAGE DO YOU HAVE FOR GIRLS AND YOUNG WOMEN FROM UNDERSERVED COMMUNITIES?

Don't let your current circumstances dictate your future. Surround yourself with the right people - people who want the best for you, lift you up, push you to do the things you're supposed to be doing and help you find yourself.

It wasn't until later in my life that I discovered that it's up to me to decide what my future looks like. I get to design my life. When you realise that you have the power to design your life, you can do anything. Imagine if money wasn't an issue, or if you didn't have any barriers, what would you want to do? Focus on that every time you have to make a decision.

A few years ago, I wrote a question on a piece of paper and put it on a wall by my desk, and I looked at it every single day. Every time I felt I couldn't do something or couldn't carry on, I looked at that question. The question was this: what is the future asking me to become? When I looked at that question, I couldn't be sad or upset; I couldn't let my current situation dictate my future. I have to look at my future and focus on that. The next question I have to ask myself is how do I make that happen?

MEET OUR YOUTH AMBASSADOR FOR ENVIRONMENTAL RESEARCH, KEHKASHAN BASU, 19, FOUNDER PRESIDENT OF THE GREEN HOPE FOUNDATION

KEHKASHAN BASU FOUNDED THE GREEN HOPE FOUNDATION, A YOUTH ORGANISATION WORKING ON UNESCO'S EDUCATION FOR SUSTAINABLE DEVELOPMENT, CHILDREN'S RIGHTS AND ENVIRONMENTAL PROTECTION, IN 2012 WHEN SHE WAS ONLY 12 YEARS OLD. SHE WILL BE PROMOTING OUR ENVIRONMENTAL RESEARCH ARTICLES TO GREEN HOPE'S 120 FUTURE ACADEMIES

YOU FOUNDED THE GREEN HOPE FOUNDATION IN 2012, WHEN YOU WERE ONLY 12 YEARS OLD. HOW DID YOU DO THAT AT SUCH A YOUNG AGE?

I have always believed that age is just a number. Any goal is achievable if one has the passion. I founded Green Hope with a handful of friends to provide a platform of engagement and grassroots-level action for children like me. I faced a lot of challenges, mainly from adults who looked at my work with cynicism and doubted the capabilities of young people like me. The turning point came in 2013, when I was elected as the youngest ever Global Coordinator for United Nations Environment Programme (UNEP)'s Major Groups for Children and Youth, making me the only minor, ever, to hold this position.

During my tenure, I successfully enhanced the engagement of young people in the UNEP stakeholder processes, thereby proving that age has no relation to capability. I have not looked back since and Green Hope has gone from strength to strength, directly empowering over 25,000 children and youth through our advocacy and capacity building programmes.

WHERE AND WHY DID YOU SET GREEN HOPE UP?

In 2012, I was one of the youngest international delegates to attend Rio+20, also known as the Earth Summit in Rio de Janeiro, Brazil. There were over 50,000 delegates at this summit, from heads of state, policy makers to civil society influencers, but only a handful of children like me. They were deciding on policies that would affect my future, yet we – children – had absolutely no involvement or say in the process. I thought this was unfair and on my return from Rio, I established Green Hope with a handful of my friends.

Our journey began in Dubai in the United Arab Emirates and, in a short seven years, we now have 1,062 youth members working in 14 country chapters across the Americas, Middle East, Africa and Asia.

WHAT KIND OF FUTURE ARE YOU HOPING FOR?

There is too much inequality in our world. On the one hand, technological advancements are breaching new frontiers while millions of children continue to die from disease and malnutrition. One in five children go to bed hungry, while millions of tonnes of food get wasted elsewhere. I want this to change and the first step is to empower the marginalised sections of civil society through education, so that they are aware of their rights and can demand the same. I am working to achieve a future that is just and equitable, and one that can sustain not only the current but future generations as well.

WHAT ADVICE DO YOU HAVE FOR YOUNG PEOPLE WHO WANT TO DO SOMETHING ABOUT CLIMATE CHANGE AND THE ENVIRONMENT, BUT DON'T FEEL THEY HAVE THE SKILLS OR POWER TO START UP MOVEMENTS LIKE GREEN HOPE?

The Intergovernmental Panel on Climate Change 2018 report has ominously stated that mitigation of climate change is possible only with the engagement of every individual and all sections of civil society. Creating a sustainable future is every person's responsibility. Therefore, it is imperative for each one of us to start taking actions within our zones of influence. Every action, however small, counts. It can be a simple step like reducing one's waste by half, or planting one tree, or stopping using plastic. The options are numerous – it is important to take action rather than just talk about it. That is the message I convey during our "Environment Academies", whether it is in a school in Canada or in the Rohingya refugee camps in Bangladesh.

FUTURUM'S AIM IS TO INSPIRE YOUNG PEOPLE LIKE YOU INTO STEM (SCIENCE, TECHNOLOGY, ENGINEERING AND MATHS) CAREERS. WHICH SUBJECTS DID YOU STUDY AT SCHOOL, COLLEGE AND OR UNIVERSITY?

STEM and the environment have a natural connection and I actively explain its usage and implications at our advocacy workshops. We use innovative modes of communication – art, music, dance, sport and drama – to spread awareness, and these tools help us to surmount language and social barriers, too.

I studied English, French, maths and science in school, and I am currently a second-year student at the University of Toronto, majoring in Environmental Studies.

FINALLY, WHAT DO YOU DO WHEN YOU WANT TO RELAX?

Music and reading help me to relax. I play the piano, guitar and drums and I also sing. However, my greatest relaxation is being with my Green Hope team doing what I love the most – empowering young people in the sustainable development process.

Green Hope has over 1,000 youth members working worldwide.

CAN WE TRUST WHAT WE SEE ONLINE?

WEBSITES USE ALGORITHMS TO RECOMMEND MUSIC, TV AND FILMS THAT YOU'LL ENJOY. BUT THEY COULD ALSO BE MANIPULATING US AND HIDING THE TRUTH. **DR ELVIRA PEREZ VALLEJOS** FROM THE **UNIVERSITY OF NOTTINGHAM** IS EXAMINING HOW TECHNOLOGY CAN BE MADE MORE TRUSTWORTHY

IMAGINE THIS

1. The news stories you see on social media are placed there by computer algorithms. Humans may be able to manipulate algorithms to spread negative stories about politicians they don't like. In turn, this may put people off voting for them.

2. When you search a travel-booking website for hotels, you'll be shown a list of top deals. But some hotels pay booking websites to appear higher up the rankings. In other words, you may not see the very best deals.

Imagine if youth juries – groups of 16 to 25-year-olds – could help governments bring in new rules to stop these types of behaviour!

Think back to the last time you listened to music on your phone. Your app probably suggested more artists you might enjoy, based on what you've listened to before. The same kind of recommendations are everywhere, from streaming services suggesting new TV shows to stores offering more things to buy.

How do these recommendations work? They're constructed using algorithms – sets of instructions that tell computers what to do. Algorithms can tailor recommendations to your personal taste by using sophisticated artificial intelligence (AI) software. The recommendations aren't always perfect, but the machines learn and get more accurate over time.

Making these algorithms trustworthy and fair is the goal of Dr Elvira Perez Vallejos, Associate Professor of Digital Technology and Mental Health at the University of Nottingham. Elvira is involved in a project called ReEnTrust: Rebuilding and Enhancing Trust in Algorithms.

ARE ALGORITHMS A GOOD THING?

If they help you find more good music, movies and TV, then yes! But they're also used to decide which stories we see on social media. Those stories might be biased in favour of a certain company or individual, or they might even be fake news! How can we tell if algorithms have been designed to manipulate us? How do we know that the information we see is accurate and fair? "If you aren't exposed to challenging views that contradict your own, you end up with a 'bubble effect' that prevents you from being exposed to other opinions," says Elvira.

CAN ALGORITHMS "SPY" ON US?

New technologies like AI and machine learning are harnessing more data about us than ever before. We agree to give away this data when we accept the terms and conditions after downloading an app. It's not surprising that few people read these terms and conditions because they're so long! According to Elvira, the danger is that the data will be used to predict your behaviour – and not always in a good way. "It could be used to manipulate people's opinions, let them only apply for specific jobs or prevent them being able to access health insurance," she explains.

DR ELVIRA PEREZ VALLEJOS

Associate Professor
Digital Technology and Mental Health
Faculty of Medicine & Health Sciences
University of Nottingham, UK

FIELD OF RESEARCH

Digital Technology and Mental Health

RESEARCH PROJECT

ReEnTrust: Rebuilding and Enhancing Trust in Algorithms is exploring ways to give users confidence in websites and social media platforms. It will examine how technology can be designed to be more trustworthy.

FUNDERS

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https://reentrust.org/
https://www.horizon.ac.uk

HOW WILL REENTRUST HELP?

Elvira and researchers at the universities of Nottingham, Oxford and Edinburgh will carry out experiments with a specially designed online tool. The tool will allow users of various platforms to say how much they trust what they're presented with. The results will be discussed with the companies behind the platforms in an effort to make algorithms more trustworthy and to make it easier for users to understand how their data is used. Ultimately, the research could lead to a "trust index" of platforms to make their trustworthiness clear to everyone. Elvira says: "We are trying to provide people with tools that give them more control over the information they consume. There will be options and settings that give users a greater or lesser degree of personalisation."

The project will also look at whether the government should bring in new rules for the companies behind digital platforms. It will do this by gathering opinions at "youth juries", workshops at which young people are invited to discuss online platforms. These will follow a similar format to Elvira's other studies: information about which can be found on the Horizon website. At the workshops, 16-25 year olds will share their experiences of searching for information, making bookings and buying products online. Elvira and her colleagues will then discuss the findings of the workshops with policymakers, as she explains: "We'll create a direct channel between young people and those who work in central government so that their voices can be heard."

The UnBias Team (from left to right): Dr Ansgar Koene, Dr Sofia Ceppi, Dr Virginia Portillo, Dr Elvira Pérez Vallejos, Mrs Monica Cano & Dr Liz Dowthwaite

ABOUT DIGITAL TECHNOLOGY AND MENTAL HEALTH

Can using your phone affect your mental health? It's often said that too much screen time is a bad thing, and some scientific research suggests that's true. The precise nature of what you see on social media can also change how you feel. But on the flipside, phones and social media have positive benefits. Part of Elvira's research involves looking at whether the design of online platforms can affect your state of mind – for better or worse.

WHY DO WE SPEND SO MUCH TIME ON SOCIAL MEDIA?

Partly because we enjoy it! But there's no doubt that social media and other apps are designed to make us want to use them for longer. The choice of colours, notifications, and "likes" all make social media a habit-forming activity it's hard for many people to break. A small number of people may even be diagnosed with social media addiction by their doctors. Elvira is interested in looking into designs that give users more control over their use of the internet.

WHAT ARE THE POSSIBLE NEGATIVE EFFECTS?

Teenagers who are heavy users of digital devices are twice as likely to show symptoms of ADHD (attention-deficit/hyperactivity disorder), according to a study in California. Another recent study in the US looked at the link between social media use and depression in adults aged 19-32. It found that the more frequently they checked social media, the more likely they were to be depressed. In the UK, a YouGov survey found that 46% of 16-25 year olds said they felt inadequate when they compared their lives with those of others on Instagram, Facebook and Twitter. And 57% said that using social media made them feel "overwhelming pressure" to succeed. There's also evidence that the time teenagers spend socialising in person – at parties, sports and other events – is 16 minutes less per day than it was 10 years ago.

DOES DIGITAL TECHNOLOGY HAVE POSITIVE BENEFITS?

Yes. Online communities can be a good way of talking to other people about mental health. You can access people who can give you support instantly through your phone or computer. Depressed people might not feel up to leaving the house, but they can still send messages. According to the charity Mind, four in five people find it useful to talk about mental health and the internet gives us the opportunity of instantly doing just that. It's also likely that social media doesn't affect everyone in the same way. Just as not everyone who plays poker becomes addicted to gambling, social media may not cause you any ill effects.

IS THERE ANY CLEAR-CUT ADVICE ON HOW WE SHOULD USE TECHNOLOGY?

In a word, no. According to Elvira, not enough scientific evidence has been gathered on the effects of the internet on our lives. That's why, together with her colleagues, she's developing a way of measuring online wellbeing. It will look at how people feel before and after using the internet for a set period of time.

OPPORTUNITIES IN DIGITAL TECHNOLOGY AND MENTAL HEALTH

- Elvira works in a multidisciplinary field, encompassing both digital technology and mental health.
- With thousands of new jobs predicted each year, there's never been a better time to start a career in digital technology. In the UK, the average salary in this sector is £37,500 compared to a national average of £28,000.
- The UK government runs an apprenticeship scheme in digital technology, suitable for students aged 16 and over.
- There are loads of summer camps that focus on digital technology. Check out TechCamp, Fire Tech Camp and iD Tech.
- If you're interested in doing research in psychology or mental health, check out the Careers in Psychology or the Psychology School Guide websites.
- The average salary for a research psychologist in the UK is £40,000.
- Voluntary work or work experience can help when you apply for a psychology degree. Childline, Mind, Rethink Mental Illness and many charities all offer voluntary work. The NHS offers work experience placements.
- Be a part of Elvira's research project by becoming a member of a "youth jury": https://reentrust.org/2019/04/05/reentrust-are-recruiting-for-citizen-juries/

ASK DR ELVIRA PEREZ VALLEJOS

WHAT DID YOU WANT TO BE WHEN YOU WERE YOUNGER?

I'm from Spain and when I first read the word "psychology", I didn't understand why it had a "p". I was intrigued. When I found out that it was the study of the human mind, I thought that was amazing. From then on, I wanted to be a psychologist and I haven't changed my mind! In particular, I'm fascinated by language. Language is such a complex activity for the brain – both to produce language and to understand speech. I'm very interested in how people describe situations, and how their opinions change. It's a fascinating topic.

WHAT SORT OF STUDENT WERE YOU AT SCHOOL?

I was very responsible when it came to schoolwork. I remember that when I got home, the first thing I'd do was my homework so that it was out of the way. I never considered myself to be a clever person but I worked hard. I remember thinking that in a class of, say, 30 people, there'd be three or four who were naturally clever. They seemed to remember things they'd read, unlike me. I'd have to read something 10 times to remember and understand what it was about! I struggled with mathematics too, but I persevered. It was a great feeling to think: "Wow – I understand that now!", and that's what kept me moving forward.

WHAT QUALITIES DO YOU NEED TO WORK IN RESEARCH?

Nowadays, multidisciplinary research teams are valued. But that is challenging because you need to work with people who have different academic backgrounds. For example, I'm a psychologist and I work with computer scientists. That's a different field, with a terminology and culture of its own. In order to succeed, you have to build resilience and relationships. It's not just about being an academic. You have to develop interpersonal skills to help you navigate the uncertainty of not knowing exactly what you're doing until the moment when everything clicks. It's a very satisfying moment but you have to build strength and resilience to get there. Sometimes the academic world isn't as gentle as it should be and sometimes you make mistakes. But don't be afraid of failure. In an academic career, producing amazing work is about trying again and again.

HOW CAN YOUNG PEOPLE GET INTO A CAREER LIKE YOURS?

An academic career in this area entails doing an undergraduate Masters in a subject like computer science, psychology or medicine. You'd need to do a masters and then apply for a PhD to do your doctoral training. At the University of Nottingham, we have a centre for doctorial training and we welcome candidates from psychology, social care, economics and the social sciences who are interested in understanding the impact of digital technology on human behaviour. We have plenty of room for students who are passionate and dynamic and who have a vision for what they want society to be like in 30 years' time.

HOW DO I KNOW IF RESEARCH IS FOR ME?

It's easy to Romanticise what research is going to be like. The best way to find out is to get involved by doing small projects whenever you can. Some people do a project and realise that research is not for them. But others discover that it's what they want to do for the rest of their lives.

ELVIRA'S TOP TIPS FOR STUDENTS

1. Build resilience to cope with setbacks
2. Don't be afraid of failure and don't give up
3. Try small projects to see if you enjoy research
4. Develop interpersonal skills to talk to researchers with different backgrounds
5. Work hard and persevere

Youth Jury in action, facilitated by Dr Liz Dowthwaite

USING SUPERCOMPUTERS TO SIMULATE SUPER TORNADOES

DR LEIGH ORF WAS JUST FIVE YEARS OLD WHEN HIS HOME WAS STRUCK BY LIGHTNING. NOW AN ATMOSPHERIC SCIENTIST AT THE **COOPERATIVE INSTITUTE FOR METEOROLOGICAL SATELLITE STUDIES**, UNIVERSITY OF WISCONSIN-MADISON, USA, HE IS USING SUPERCOMPUTERS TO RECREATE TORNADOES, BECAUSE HAVING A BETTER UNDERSTANDING OF SEVERE WEATHER COULD ULTIMATELY SAVE LIVES

WE ASK LEIGH WHAT SPARKED HIS INTEREST IN SEVERE WEATHER

"It was an actual spark that sparked my interest! When I was five years old, shortly after my family moved into a new house in western Massachusetts, our house was struck by lightning. I remember it as if it happened yesterday. The day was unsettled, with thunderstorms all around throughout the day. In the evening, when my sister and I were getting ready to go to bed, the thunderstorms were really moving in. We lived in a two-storey Cape Cod-style house.

"Lightning struck the TV antenna that was located above my sister's bedroom and entered the electrical wiring of our house. It blew a hole in the wall of my sister's room, with panelling and burnt insulation flying across the room. The canopy on my sister's bed caught fire, and my mother was temporarily deafened by the concussion of the lightning bolt. I remember seeing glowing wires in the wall as I ran downstairs. Thankfully, there were no permanent injuries and the fire was easily extinguished. That was my first real encounter with severe weather."

A tornado is a rapidly rotating column of air that extends from a thunderstorm to the ground. The Enhanced Fujita (EF) scale is used to assign every tornado a number from 0 to 5, a figure which is determined by surveying the damage the wind speeds inflict. The destruction that an EF-0 causes is similar to that which might be caused by strong gusts, while tornadoes rated EF-4 or EF-5 – typically described as "super tornadoes" – are devastating. Fortunately, super tornadoes are the least common tornadoes and only occur on average once per year, usually in the United States.

It is still not known what causes a tornado and scientists around the world are attempting to solve this puzzle. One such scientist is Dr Leigh Orf, an atmospheric scientist at the Cooperative Institute for Meteorological Satellite Studies, University of Wisconsin-Madison in the US. Leigh has dedicated his life to finding out as much as possible about tornadoes and thunderstorms, particularly super tornadoes. "It is known that for all tornadoes, you need a thunderstorm with a strong updraft (upward current of air that is in the heart of the cloud). However, a strong updraft itself is not sufficient," explains Leigh. "There must be a source of vorticity (spin) available for the updraft to 'pull on' to form a tornado."

Simulations and observations have shown that thunderstorms contain lots of invisible swirling vortices that look like mini-tornadoes but do not cause any damage. Leigh's research has shown that these spinning vortices can aggregate beneath the updraft and form a larger, more powerful vortex that sometimes becomes a tornado. However, the whole subject of tornado formation (known as tornadogenesis) is still an active field of research.

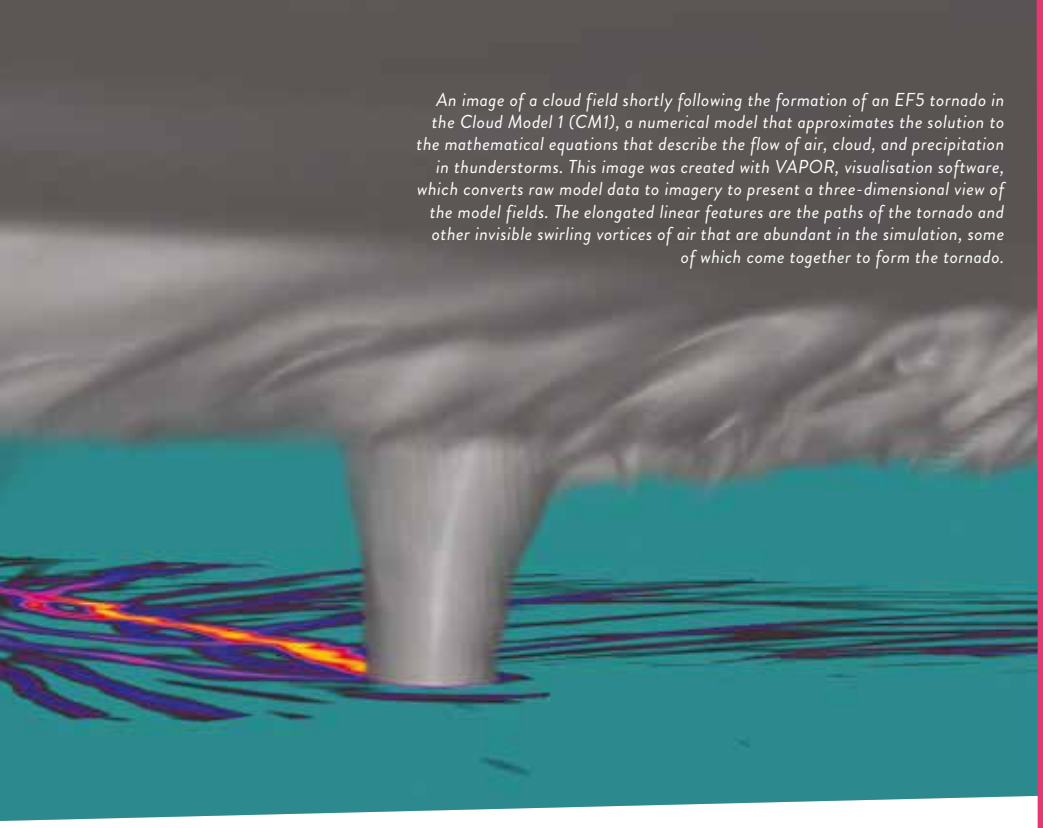
WHY DOES THE USA EXPERIENCE MORE TORNADOES THAN ANYWHERE ELSE IN THE WORLD?

According to the National Oceanic and Atmospheric Administration, more than 1,200 tornadoes a year occur in the US. The reason they are so prevalent in this part of the world is that the majority of tornadoes form within supercell thunderstorms – a special type of long-lived storm that exhibits a rotating updraft. The environmental conditions that supercell thunderstorms form within are most common in the Great Plains of the United States.

The warm, moist air from the South streaming in beneath cold, dry air from the North creates a "pressure cooker" situation where, if storms are triggered, they often form supercells, and about one in four supercell thunderstorms form tornadoes. Ultimately, it is the unique geography of the United States that results in so many tornadoes, primarily in the spring.

HOW DO SUPERCOMPUTERS HELP WITH RESEARCHING TORNADOES?

Leigh and his colleague, Bob Wilhelmson, simulated the first ever EF-5 tornado using the Blue Waters supercomputer built at the University of Illinois and sponsored by the National Science Foundation. "My research heavily utilises a numerical model, which is



An image of a cloud field shortly following the formation of an EF5 tornado in the Cloud Model 1 (CM1), a numerical model that approximates the solution to the mathematical equations that describe the flow of air, cloud, and precipitation in thunderstorms. This image was created with VAPOR, visualisation software, which converts raw model data to imagery to present a three-dimensional view of the model fields. The elongated linear features are the paths of the tornado and other invisible swirling vortices of air that are abundant in the simulation, some of which come together to form the tornado.

DR LEIGH ORF

Atmospheric Scientist
Cooperative Institute for Meteorological Satellite Studies (CIMSS), University of Wisconsin-Madison, USA

FIELD OF RESEARCH

Atmospheric Science

RESEARCH PROJECT

Leigh's research is centred on simulating and visualising tornadoes and thunderstorms by using supercomputers.

FUNDERS

CIMSS/SSEC,
University of Wisconsin,
National Science Foundation

a computer program that is programmed with the laws of physics in such a way as to allow for a 'virtual storm' to grow within a supercomputer," explains Leigh. "The model breaks the atmosphere into discrete volumes of space, and these volumes of space are updated slowly over time – sort of like watching each frame of a movie in slow motion. The time step is the space between each frame."

The numerical models Leigh uses requires that if you have very small discrete volumes (known as "high resolution") then you must have a very small time step. Too large a time step causes the model to "blow up", producing exponentially large values, causing the model to abort. This can occur when the wind speeds inside the model get too large for the chosen time step, such as when a tornado forms within the model. With Leigh and Bob's first EF-5, they chose too large a time step and the model blew up. So, they went back to an earlier point in the simulation and ran it forward with a reduced time step. The simulation ran seamlessly from that point on.

WHY IS IT IMPORTANT TO CREATE SIMULATIONS OF THUNDERSTORMS?

Many people associate tornado research with storm chasing, either recreational storm chasing (where people hope to watch and capture videos of a tornado), or research storm chasing where scientists probe tornadoes with radars and other instrumentation. This type of field research is of critical importance, as sampling the real atmosphere is required to understand real tornadoes! However, field studies of tornadoes are expensive, complicated and often very frustrating when Mother Nature does not cooperate.

Thunderstorm models offer a completely different way to study tornadoes. A good thunderstorm model takes the known laws of physics and uses them to simulate the entire life cycle of a thunderstorm, including any tornado that may form. "In our simulations we start with a set of pre-storm, 'pressure cooker', environmental conditions that would represent 'the calm before the storm' – the period shortly before thunderstorms pop up in real life," says Leigh. "We trigger the cloud in these conditions by forcing an updraft, similar to the way many storms form in nature. From here on out the laws of physics take over – we don't know what will happen at this point any more than we know what will happen when we see a storm fire up in nature."

In the majority of simulations Leigh has conducted, a supercell will form but no strong tornado will form. This is very similar to the real atmosphere where super tornadoes are extremely rare. These non-tornadic simulations are just as valid as simulations with strong tornadoes but, because they represent a more common form of thunderstorm, his research group is less interested in studying them right now.

WHAT DOES THE FUTURE HOLD FOR LEIGH AND HIS RESEARCH?

Leigh aims to simulate many more supercells in different environments where different types of tornadoes form, not just super tornadoes. His team is seeking to uncover what kinds of conditions occur in supercells that lead to the most common weak, short-lived tornadoes, as well as super tornadoes.

If they can answer those types of questions, there is hope that weather forecasters will be able to use what they learn in their simulations to create more accurate forecasts of real storms. And it is Leigh's hope that this would ultimately result in saving lives.

Tornadoes contain violently swirling air that can be represented by a quantity called vorticity. The vorticity found within the tornado is demonstrated by the solid red cylindrical feature, which is surrounded by weaker regions of rotation that would be invisible to the naked eye but may play a crucial role in the tornado's formation.

ABOUT ATMOSPHERIC SCIENCE

As the name suggests, atmospheric science is the study of the Earth's atmosphere. Research might include studying its processes, the effects other climate systems (the hydrosphere, the cryosphere, the lithosphere and the biosphere) have on the atmosphere, and the effects of the atmosphere on these other systems. It can be thought of as an interdisciplinary field of study that combines the components of physics and chemistry in order to focus on the structure and dynamics of the Earth's atmosphere.

WHAT SHOULD YOU STUDY IF YOU ARE INTERESTED IN A CAREER IN ATMOSPHERIC SCIENCE?

With the onset of climate change, atmospheric science is arguably a more important field of study than ever before. It is a challenging subject and necessitates the study of mathematics (algebra, calculus, differential equations, and maybe some linear algebra), physics, a bit of chemistry, and computer skills, including programming.

These subjects provide the bedrock foundation for classes in atmospheric science that describe how and why the air moves the way it does from large to small scales; how the radiation from the sun and greenhouse gases work to heat the Earth and keep our planet habitable, and how clouds and precipitation behave.

IS CLIMATE CHANGE CAUSING MORE SUPERSTORMS, TORNADOS AND OTHER SEVERE WEATHER EVENTS?

Currently there is no evidence that climate change is causing more tornadoes, or the supercells that spawn most of them. Simulations indicate future climates may provide more instability for supercells but less wind shear (sudden changes in wind speed or direction), and currently there is no clear signal regarding whether there will be more tornadoes, stronger tornadoes, etc. in the coming decades.

What is more certain is that there will be more droughts, wildfires, heat waves and intense flooding events. We are already seeing some of this today. Regarding hurricanes, the current understanding, primarily gleaned from model simulations, is that there will be fewer hurricanes in the future, but that, due to high sea surface temperatures, hurricanes that do form will be, on average, more intense.

ABOUT SUPERCOMPUTERS

A supercomputer is a computer that is unusually powerful compared to a typical desktop computer or laptop you would find at school or at home. The most powerful supercomputers comprise thousands of individual, identical high-performance computers connected together by a high-speed network that allows rapid communication across the entire machine.

The power of a supercomputer is often indicated by the number of floating point operations per second (FLOPS) that it can execute, with the most powerful computers currently exhibiting performance of over 10 petaflops (ten thousand million million FLOPS).

HOW MANY SUPERCOMPUTERS ARE THERE WORLDWIDE?

There are thousands of supercomputers across the globe but the typical performance is much less impressive than the top few machines.

WHO WORKS WITH SUPERCOMPUTERS?

Scientists and researchers from academia, industry and government make up the bulk of supercomputer users. The commonality between all users is that their application demands very large amounts of computer memory and/or processing power. Machines like Blue Waters are primarily available to academic researchers where scientists are running simulations of earthquakes, galaxy formation, the internal workings of stars, climate modelling and much more.

You can view a breakdown, by science category, of the usage on Blue Waters by visiting the Illinois National Center for Supercomputing Applications website: https://bluewaters.ncsa.illinois.edu/usage-fos

ASK DR LEIGH ORF

AS A SEVERE WEATHER EXPERT, HOW CLOSE DO YOU GET TO TORNADOES AND OTHER EXTREME WEATHER EVENTS?

My own research does not directly involve field work, so I do not go to where the storms are. To be honest, I think my early encounters with severe weather have made me a bit fearful of these powerful storms - I do not like being near lightning and tornadoes! However, I collaborate with many enthusiastic field researchers who have a real passion for real storms, and they chase storms, both for fun and for research. The data they collect in the field is vitally important to my own research in that it helps validate (or not!) my model results. I do many comparisons between my simulation data and observed data - both are vitally important in helping scientists understand the inner workings of tornado-producing thunderstorms.

YOU HAVE A DEGREE IN METEOROLOGY AND A PHD IN ATMOSPHERIC SCIENCE. WHERE DID YOU GET THE EXPERTISE TO WORK WITH THE BLUE WATERS SUPERCOMPUTER?

Supercomputers run the Linux operating system. While I took computer programming courses in college, my experience with Linux was all self-taught. I first learned how to install and use Linux on a "normal" computer, the one I used in my office to do research, when I started graduate school. Eventually I got access to a research supercomputer where I learned how to compile code and submit jobs to the queue. Since supercomputers are shared resources, everybody is competing for usage of the machine, and there is a system for submitting your jobs to be run. While there is lots of online documentation for the supercomputer I use, there are many training courses also available to scientists because of the complexity of the machines and the rapidly changing hardware you encounter for each new supercomputer. There are also staff who work to help researchers out when they run into problems.

But, for me, I mostly just figured stuff out because I have a passion for it and really enjoy using as much of the supercomputer as I can to solve problems that can only be solved this way.

KNOWING WHAT YOU KNOW ABOUT SEVERE WEATHER AND CLIMATE CHANGE, HOW OPTIMISTIC ARE YOU ABOUT THE FUTURE?

Frankly, I think we are in for a very rough ride. We have not made the changes we needed to make regarding fossil fuel use to stave off significant climate disruption for human society. We are already seeing the effects of this today, and yet we continue to pump record amounts of greenhouse gases (primarily carbon dioxide) into the atmosphere. The alarm bells from scientists ring louder and louder but the response has not been sufficient enough to keep climate from changing in a very significant way.

Over the next hundred years we are going to see extinctions on a massive scale not seen for millions of years, and huge disruptions in human society as climate forces people to migrate to more habitable locations. However, we still have time to make major changes to fossil fuel emissions to stave off the absolute worst-case scenario, but time is running out very quickly.

OPPORTUNITIES IN ATMOSPHERIC SCIENCE

- Atmospheric scientists in the US earn an average salary of around $94,000 per year, with wages typically starting from $50,000 up to around $142,000.
- Environmental Science has a website dedicated to explaining exactly what atmospheric scientists do and the requirements for getting into the field.
- SuccessfulStudent.org explains some of the best graduate programmes for the atmospheric sciences in America.

LEIGH'S TOP TIPS

ATMOSPHERIC SCIENCE:

01 – A degree in meteorology or atmospheric science is highly recommended if you are sure you want a weather-related career. However, it is possible to gain a degree in physics or mathematics and enter graduate school in atmospheric science.

02 – Take as many science-related courses – specifically in physics, maths and computer science – as you can before you go to college.

SUPERCOMPUTERS:

01 – You should learn how to program. It isn't very important which language you use at first – it's more important to first learn programming concepts and proper programming practices.

02 – For students who are interested in supercomputers, using Linux is your best bet, as that is the operating system of virtually all supercomputers. Linux is free and can be installed on almost any computer.

FROM PLATINUM TO SMARTPHONE: HOW MATHS MODELS CAN BE USED TO STREAMLINE SUPPLY CHAINS

WHETHER IT'S THE RUBBER IN YOUR NIKE TRAINERS, THE METALS IN YOUR IPHONE OR THE SUGAR IN YOUR COCA-COLA, RAW MATERIALS SUCH AS THESE GO THROUGH A SERIES OF STEPS IN A SUPPLY CHAIN TO END UP IN A SHOP NEAR YOU. BUT WHAT HAPPENS IF ONE OF THESE STEPS FAILS? AT **LEHIGH UNIVERSITY, PROFESSOR LARRY SNYDER** IS USING OPERATIONS RESEARCH AND MACHINE LEARNING TO PROTECT THESE VITAL SUPPLY CHAINS

TO MAKE SLIP-ON SHOES, VAN'S HAS TO SOURCE MATERIALS FROM OVER 75 DIFFERENT SUPPLIERS WORLDWIDE!

ANYTHING COULD GO WRONG AT ANY POINT. WITHOUT PROPER MANAGEMENT, PROBLEMS IN THE SUPPLY CHAIN CAN CAUSE HOLD-UPS IN SHOE PRODUCTION, DISTRIBUTION AND SALES. MANAGING THIS CHAIN IS MASSIVELY IMPROVED WITH COMPUTER MODELLING AND OPERATIONS RESEARCH.

(source: https://sustainability.vfc.com/our-impacts-efforts/responsible-sourcing/traceability)

Every organisation, whether a restaurant or hospital, depends to some extent on factors out of their control: workers in another factory, a cargo ship departing punctually, the weather. The sequence of steps required for a product or service to make it from the development stage to sale is called a supply chain. Larry Snyder, Professor of Industrial and Systems Engineering at Lehigh University, uses operations research to build computer models that can optimise and protect these supply chains.

WHAT IS SUPPLY CHAIN MANAGEMENT?

Supply chain management is the management of the flow of goods from the source of the raw materials, through to the production process, all the way to the consumer. A supply chain ends with a customer getting the product or service they want. Think of coffee beans in Costa Rica, for example, and all of the processes that need to happen to turn these coffee beans into coffee that can be sold in coffee shops or supermarkets. There are a lot of hidden steps that consumers never see, from the harvesting of the beans to the processing, packaging and transportation. But what happens if floods damage the crops in Costa Rica, or a fire breaks out in the processing factory? A failure at any stage in the supply chain can cause a chain reaction, delaying later steps, and creating a shortage at the consumer end – this is known as supply chain disruption. Good supply chain management is about creating supply chains that can withstand these disruptions without leading to a shortage of supplies or services.

PROF LARRY SNYDER

Professor of Industrial and Systems Engineering
Lehigh University, USA

FIELD OF RESEARCH

Industrial and Systems Engineering

RESEARCH PROJECT

Larry uses computer models to help businesses protect their company from unforeseen supply problems.

FUNDERS

National Science Foundation (NSF), Department of Energy (DOE), Lehigh University

HOW CAN OPERATIONS RESEARCH BE USED FOR SUPPLY CHAIN MANAGEMENT?

The mathematical tools of operations research can be used to analyse a supply chain and help it to run as efficiently as possible. "Imagine you own a bakery," says Larry. "You bake bread each morning, but you don't know in advance how much will be bought that day. If you bake too few loaves, you'll miss out on some potential profit. But if you bake too many, you'll be left with stale bread. Striking the optimal balance – the number of loaves that will maximise your average profit per day – requires some probability and some calculus." This is a classic operations research problem called the newsvendor problem – newspapers, like bread, go "stale" after a day.

WHAT CAUSES SUPPLY CHAIN DISRUPTION?

Events such as natural disasters, equipment failure or strikes can cause supply chain disruption. Using operations research for supply chain management doesn't just mean making sure that the chain will have optimal results when everything is going to plan – it means that supply chains can be designed to withstand disruption, so that an unforeseen problem at one step doesn't bring the whole supply chain to a halt.

Larry develops computer programs, or algorithms, which model supply chains for different organisations. Using these algorithms, he helps organisations to optimise their supply chains and withstand any difficulties they encounter.

HOW CAN MACHINE LEARNING HELP IN SUPPLY CHAIN MANAGEMENT?

Machine learning is a technique where a computer program is "trained" to make decisions. Recently, Larry's team has been investigating ways that machine learning can be applied to help make better decisions in supply chains. Larry explains: "For example, if you had lots of data about the demand for bread at your bakery on different days of the week, in different weather conditions, and so on, you could train a machine learning algorithm to make better decisions about how much bread to bake." Larry also uses machine learning to predict shortages in the supply chain, and to decide what routes delivery trucks should take.

Machine learning is a useful tool in operations research, the purpose of which is to help people tackle challenging problems. With applications in healthcare, business and disaster relief, a career in the wider field of operations research could offer you the chance to make a difference in an area important to you.

OPPORTUNITIES IN OPERATIONS RESEARCH

- Pathways to Science offers a summer programme for high school students interested in learning about computer science and maths, including operations research
- INFORMS develops instructional materials for teaching operations research in high school
- The National Security Agency offers internships and other career opportunities in operations research
- You can find free online courses in operations research on websites like Coursera and OR Complete
- On average, an operations research analyst in the USA earns $75,770 per year

ABOUT OPERATIONS RESEARCH AND MACHINE LEARNING

Operations research is a set of mathematical and computational tools for evaluating, analysing and optimising complex systems. In other words, these tools help systems run as efficiently as possible, and continue to work well during unforeseen problems such as natural disasters, strikes or equipment failure. Operations research is used by companies in nearly every industry, as well as by governments and non-profit organisations. "Whenever an organisation has a problem with huge numbers of possible combinations or lots of randomness, operations research can help," says Larry. He lists the following examples:

- Airlines use operations research to decide where to fly and when, which aircraft to fly on which flights, and which pilots to assign to each flight.
- Hospitals use operations research to improve the efficiency of patient flows, to manage the inventory of life-saving supplies, and to schedule operating rooms.
- Non-profit organisations use operations research to decide how to get relief supplies to disaster victims quickly, how to allocate resources fairly, and how to plan evacuation routes.

WHAT IS MACHINE LEARNING?

"Even though the phrase 'machine learning' conjures up images of cyborg butlers and computerised doctors, it's really just a set of computer programs, or algorithms, which help computers perform tasks that are traditionally thought of as part of human intelligence. For example, machine learning algorithms have recently gotten good at identifying images, translating text and even playing computer games!" says Larry.

"Imagine you want to write an algorithm to play chess," Larry continues. "One approach would be to build certain fixed rules or preferences into the algorithm, like 'it's worse to lose your queen than your rook' or 'it's good to double your opponent's pawns.' Machine learning algorithms, though, don't tend to be rule-based. Instead, they're designed to 'learn' which moves are good or bad on their own without being told explicitly. They do this either by analysing a large volume of data, or by simulating a task (like playing chess) many, many times and learning what works and what doesn't."

However, as Larry says, "Machine learning is one of many tools in the operations research toolbox. It's a hugely powerful tool for some jobs, and not the right tool for others."

IF COMPUTERS CAN ANSWER COMPLEX MATHS PROBLEMS FOR US, WHY SHOULD STUDENTS CONSIDER STUDYING MATHS?

Computers are really good at calculations, but maths is about much more than number crunching. "If you want to write a computer program that will design a bridge, you have to understand structural engineering before you can write the program. If you want to write an autopilot program for an aeroplane, you have to understand aerodynamics," says Larry. "By the same token, if you want to write a program to solve maths problems, you have to understand the maths."

The importance of human input into operations research is highlighted by a famous operations research problem: the travelling salesman problem. "You are given a set of cities, and you have to find the shortest route that visits every city (and returns to the starting point)." Explains Larry, "One naïve way of solving this problem is to program a computer to try every possible sequence of cities and pick the shortest one. If there are n cities, then there are n! (n factorial) sequences. If your travelling salesman needed to visit 50 cities and your computer could check 1 quadrillion sequences per second, it would take your computer over 964,424,568, 801,000,000,000,000,000,000,000, 000,000,000 years to solve the problem!"

Human input, in the form of operations researchers, is essential. More complex algorithms need to be designed to solve problems such as this one. "Today's algorithms can solve a 50-city travelling salesman problem in a fraction of a second," says Larry. "Those algorithms use lots of maths, especially fields like combinatorics, linear algebra, and real analysis."

Understanding maths is a crucial part of operations research. However, there are a lot of different routes to operations research, including engineering and physical sciences. Also, because operations research isn't typically taught in high school, university level courses don't assume that their students already understand the maths behind operations research.

ASK PROF LARRY SNYDER

WHAT DO YOU LOVE ABOUT MATHS?

Maths is about problem solving, about coming up with creative ways to solve problems. I think a lot of people don't like maths in high school because they think it's all about recipes: if you encounter a problem that looks like this, then you should solve it by following these steps. In college, maths is much more creative. If you want to come up with a way to solve maths problems, you have to understand the underlying maths. There's a lot of logic, a lot of trial and error, and a lot of experimentation involved. In fact, doing research scratches the same part of my brain that itches when I solve (or write) puzzles.

WHY DIDN'T YOU WANT TO CONTINUE TO WORK IN PURE MATHS AFTER YOUR UNDERGRADUATE DEGREE?

Actually, I knew even at high school that I wanted to go into operations research after my undergrad degree. I loved maths at high school, but I didn't really know what sort of careers were possible if I majored in maths in college. Then a graduate of my high school, who works in operations research, gave a talk about operations research to my calculus class. I was hooked immediately.

WHAT WAS IT THAT GRABBED YOUR ATTENTION ABOUT OPERATIONS RESEARCH?

I loved the idea that maths could be applied, and applied to interesting businesses like airlines and health care, so I knew I wanted to go into operations research. But I also really wanted to go to Amherst College, which doesn't have an operations research programme. So, I decided to major in maths at Amherst, then switch to operations research in graduate school, and it worked out great.

WHO HAS INSPIRED YOU THE MOST THROUGHOUT YOUR CAREER? OR IN YOUR CHOICE OF CAREER?

I was fortunate to have a few really good maths teachers in high school, who helped me see the non-recipe side of maths earlier than some students do. I also had terrific maths professors in college, who encouraged me to find my way to operations research even though it wasn't part of the curriculum. They taught me to enjoy the slight feeling of vertigo you get when you start down the path of an idea, but you don't quite know how solid it is or which way it's heading. They also taught me, by example, how much fun it is to teach. And also that maths jokes are awesome!

LARRY'S TOP TIPS FOR STUDENTS

1. Take the maths classes that interest you! Every maths class is going to stretch your brain in useful ways, and prepare you to think about whatever new kinds of problems you'll discover later.
2. When you do maths, let your mind wander. Let yourself think about problems in ways that your teacher didn't suggest.
3. Explore the ways that maths is linked to your other interests. Maths has a role to play in everything, whether that be music, coding, or even planning out a paper route.

LARRY'S FAVOURITE MATHS JOKES!

- A mathematician, an engineer, and a physicist are riding a train through Scotland when they pass a black sheep. The engineer says, "Apparently Scottish sheep are black." The physicist says, "No, all we can say is that *some* Scottish sheep are black." "No, no," says the mathematician, "all we can say is that some Scottish sheep are black *on one side*."
- "A mathematician is a device for turning coffee into theorems." Quote from the mathematician Alfréd Rényi

HOW TO RAISE A MATHS GENIUS

ARLO TAYLOR IS 12 YEARS OLD AND IS ALREADY STUDYING FOR A MATHS DEGREE WITH THE UNIVERSITY OF NEW ENGLAND IN AUSTRALIA. WE ASK ARLO, HIS MUM JULIA AND HIS FORMER PRIMARY SCHOOLTEACHER, BEN MCCULLOCH, WHAT IT MEANS TO BE A GIFTED CHILD

ARLO TAYLOR

YOU'RE STUDYING MATHS AT THE UNIVERSITY OF NEW ENGLAND AT THE AGE OF 12! WHAT'S IT LIKE DOING AN ONLINE DISTANCE COURSE AT SUCH A YOUNG AGE?

Being at university at this age is fun. It is only stressful towards the end of the semester, but even then, it is manageable. I'm not on campus so I just study in class alongside my peers, so to me it's just like doing normal school work, but way more fun and interesting.

WHICH PART OF YOUR MATHS COURSE DO YOU ENJOY THE MOST?

I love learning in general and there is so much learning to do at uni! My favourite area of maths is multivariable calculus, so learning about things like double integrals, partial derivatives, directional derivatives and Stokes' Theorem has been awesome!

DOES YOUR HEAD FOR MATHS HELP YOU WITH ANY OTHER SUBJECTS OR HOBBIES?

No, maths is completely useless (just kidding). Yes, it applies to many other areas of life. The higher order thinking it requires is useful to all learning and thought; and learning about the beginnings of mathematics has helped me to develop an understanding of general history and culture over the ages.

DO YOU KNOW WHAT YOU WANT TO BE WHEN YOU'RE OLDER?

I want to be a mathematician when I'm older. When I was younger, I would read books about mathematicians from the past and see them as my idols. So, I guess this has always been my goal.

NOT EVERYONE IS A MATHS GENIUS. IN FACT, A LOT OF PEOPLE THINK THEY CAN'T DO IT. DO YOU HAVE ANY TIPS OR ADVICE FOR THEM?

Don't worry, no one can be great at everything. Just because you may not be especially skilled in mathematics, does not mean you cannot pursue your dreams. Maths is like everything else: practise makes perfect.

WE HAVE HEARD THAT YOU ENJOY PLAYING THE ELECTRIC GUITAR. WHAT SORT OF MUSIC ARE YOU INTO?

I like grunge music and alternative rock. Some of my favourite bands are The Offspring, Metallica, Helmet and Something for Kate.

ARLO'S MUM

JULIA TAYLOR

WHEN AND HOW DID YOU FIRST REALISE THAT ARLO HAD AN EXCEPTIONAL GIFT FOR MATHS?

Looking back, I can see now that Arlo's high intelligence was evident from when he was very young, but at the time, as a young mum, I wasn't aware that his development was anything out of the ordinary. When our second child was born, a nurse come to visit our new baby, but she spent most of her time watching Arlo, who was 22 months old. She indicated that his play (creating complex patterns with his toys, the repetition in his play, long time periods on the same task, etc.) was quite unusual for his age. When Arlo was three I started taking him to a local play group and, for the first time, it was very obvious to me (and others) that he was quite different to the other kids – for example, while the other 3-year-old boys zoomed their trucks around the sand pit making motor noises, Arlo spent his time figuring out how the trucks' axels worked.

IN WHAT WAYS HAVE YOU NURTURED THIS GIFT?

In our household, Arlo is the only lover of maths! We realised we would have to find ways to support him outside of what we could offer at home; for example, over the years, we have picked up many books about maths that Arlo has pored over since he was quite young. Arlo is fortunate to have a grandfather who was high achieving in mathematics at school, so when Arlo was aged 9, he started Skyping him regularly to talk/learn more about maths. The internet has been a brilliant resource for Arlo, from maths YouTube channels to online maths articles.

WHAT CHALLENGES HAVE YOU FACED RAISING A GIFTED CHILD, AND HOW HAVE YOU OVERCOME THEM?

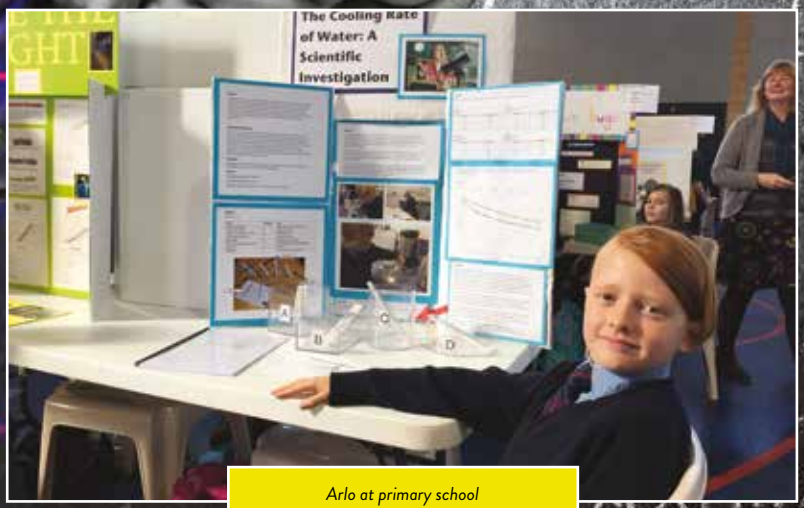
Ensuring Arlo is stimulated in the school setting has been a challenge at times. We found that when Arlo was not sufficiently stimulated in maths and science, he would lose interest in all other subjects, too. Arlo went to a very supportive primary school and we were able to develop a flexible programme that combined online learning with classroom education – and we have continued this into high school: Arlo studies maths and science online and everything else with his peers.

WHAT ADVICE DO YOU HAVE FOR OTHER PARENTS WHO THINK THAT THEIR CHILD MAY HAVE A SPECIAL TALENT LIKE ARLO'S?

Be guided by your child! For us, it has always been really important for Arlo to maintain his love of maths and his intrinsic motivation for it. We have always ensured that he is the driver of his extended learning and it is never forced upon him. Arlo's talents do not go unnoticed by his peers, educators and pretty much everyone around him. This is great, but it can also mean that he has very high expectations placed on him. As parents, we do our best to support him to reach his goals without these high expectations. Also, learning about gifted education and current research around how to support gifted and talented students in the school system is important. This allowed us to advocate effectively for Arlo and develop a flexible learning programme that means his social experiences remain with his age group, but his learning in the areas of his strengths is not limited.

WHAT ARE YOUR HOPES FOR ARLO'S FUTURE?

We hope that Arlo has a colourful life filled with all the ups and downs and experiences that will enrich him as a person. Maths is just one small part of who Arlo is. Whether his path involves mathematics or some other direction all together, we are now, and will always be, immensely proud of him.



Arlo at primary school

> "WE FOUND THAT WHEN ARLO WAS NOT SUFFICIENTLY STIMULATED IN MATHS AND SCIENCE, HE WOULD LOSE INTEREST IN ALL OTHER SUBJECTS, TOO."

ARLO'S FORMER MENTOR AND PRIMARY SCHOOLTEACHER

BEN MCCULLOCH.
VICE PRINCIPAL,
ST BRIGID'S CATHOLIC PRIMARY SCHOOL

HOW DID THE SCHOOL LEARN ABOUT ARLO'S GIFT FOR MATHS?

From a very young age Arlo displayed advanced cognitive development, and he had a particular inquisitiveness for all things' science. Arlo's family fostered a close relationship with the school, enabling a partnership that would continue to blossom throughout his primary education. Frequent communication, the engagement of external professionals, and the analysis of assessments allowed the school to build a clear profile of Arlo's needs, particularly his gift for mathematics. We knew that without quality enrichment Arlo was at risk of disengaging from his learning.

WHAT SUPPORT DID THE SCHOOL PUT IN PLACE FOR ARLO?

In 2015, as Arlo's Year 4 teacher, I received a scholarship from the Tasmanian Association for the Gifted and completed a Certificate of Effective Practice in Gifted Education. This practical study provided me with vital knowledge and skills to better cater for and understand Arlo's needs. Throughout the remainder of his primary education our key objectives were for Arlo to remain cognitively stimulated in mathematics and science, and for him to maintain meaningful relationships socially with his peers. An example of what learning looked like in mathematics for Arlo in Year Four was that while his peers were learning to read analogue time, he was learning to calculate the velocity of a moving object.

In Year 5, Arlo accessed accelerated learning, engaging in the Year 10 mathematics curriculum and completing Year 12 maths and science by the end of Grade 6. He also attended gifted workshops where he engaged with gifted peers and mentors. As a Code Club Australia and LEGO FIRST Robotics Coach, I actively encouraged Arlo to develop his skills in visual programming. His exceptional computational skills and love for problem solving went hand in hand with computer science, for which he quickly developed a passion. As an educator and one of his key mentors, I quickly learned that it was okay not to be the expert in the room. My role was to provide the opportunities for Arlo to engage in purposeful and challenging experiences that have a strong connection with science, technology, engineering and mathematics.

Between 2015-2017, when Arlo was 7-10 years old, he received awards as part of the University of Tasmania's Science Investigation Awards. In the 2016 Tasmanian Science Talent Search, Arlo was awarded the Australian Institute of Physics Tasmanian Branch Award – "Best Primary Physics Project on Light Work: Refraction, Wavelength and Speed". In 2017, Arlo received an award for Outstanding Achievement in the Australian Mathematics Trust Awards.

WHAT ARE THE CHALLENGES OF TEACHING A GIFTED AND TALENTED CHILD?

The first challenge is identification. The diversity of gifted characteristics can make it difficult to identify giftedness. This is exacerbated by the fact that the term "gifted and talented" is often ill-defined. Broad based procedures are required to ensure we pick up those children that may not immediately strike us as falling into the gifted category. Unfortunately, this knowledge base is not present in all schools and systems. In Arlo's case, he experienced slow processing challenges early on, which was incongruent with his high academic aptitude. Many gifted and talented children can be "twice-exceptional" where their giftedness is accompanied by evidence of one or more disabilities. Misdiagnosis is a threat as academic performance is often inconsistent, such as

> "AS AN EDUCATOR AND ONE OF ARLO'S KEY MENTORS, I QUICKLY LEARNED THAT IT WAS OKAY NOT TO BE THE EXPERT IN THE ROOM."

difficulties with written expression. Such a case can hinder a child's engagement in learning and have a detrimental impact on their motivation, self-efficacy, dignity and well-being.

Another significant challenge can be balancing academic advancement with critical social skills. Holistic education is key for the well-being of gifted children. Opportunities to work alongside children of similar academic abilities is just as important as opportunities to participate socially with age-equivalent peers. The notion of accelerated learning can be met with angst and fear; however, a strong partnership between home and school can ensure that all needs of the child are met.

IN WHAT WAYS HAVE ARLO'S PEERS AND OTHER SCHOOL CHILDREN BENEFITED FROM THE SCHOOL'S GIFTED AND TALENTED PROGRAMME OF SUPPORT?

Enrichment is one of our key teaching strategies. Engaging students in real-world problem solving, promoting higher order thinking, inquiry and the development of soft skills such as creativity, communication, collaboration and critical thinking benefit all children, not just the gifted and talented! The integration of curriculum in a meaningful way nurtures a culture and love of learning. This was the case for Arlo and his peers. His love of learning emanated throughout the class. All children, including those who are gifted, want to make a difference and, by participating in authentic learning experiences, children are encouraged to help create a preferred future.

WHAT ADVICE DO YOU HAVE FOR OTHER TEACHERS AND SCHOOLS WITH GIFTED AND TALENTED CHILDREN?

Be supportive and flexible to meet the needs of the child. Don't leave any door unopened. Early intervention and support are critical to ensuring the well-being and academic performance of all children. Evidence-based, high quality learning and teaching can go a long way to engaging the gifted and talented. We must draw on a mixture of behavioural characteristics, levels of performance (both under and over) and the presence of gifted traits to get a clear picture of a child's strengths and learning needs. As a teacher, if you are unsure, be vulnerable and reach out for assistance. We have a shared responsibility to cater for all students to ensure they learn at high levels.

Moreover, what you put in will come back to you tenfold. The reward you get from seeing a child flourish is invaluable. Seeing Arlo complete his first year of pure mathematics at the University of New England and receive the school prize in Mathematics and Computer Science for "the most distinguished results" is very fulfilling. Even more importantly, he is a really happy guy, connected with friends and family and loving his music.

Finally, the work of Arlo's parents, Julia and Ned – their loving disposition – has created the conditions for him to flourish.

Ben with his students at St Brigid's Catholic Primary School

Students at St Brigid's Catholic Primary School

TAP INTO AN EU BOUNTY OF FREE SCIENCE EDUCATION RESOURCES

RATHER THAN RELENTLESSLY CREATE AND SEARCH FOR USEFUL SCIENCE EDUCATION RESOURCES, SCHOOLS AND TEACHERS CAN TAP INTO **SCIENTIX**, A EUROPEAN-WIDE SCIENCE EDUCATION COMMUNITY THAT OFFERS A BOUNTY OF CLASSROOM ACTIVITIES, LESSON PLANS, CPD, NETWORKING EVENTS AND MORE – ALL OF WHICH HAVE BEEN STUDIOUSLY CREATED BY EU-FUNDED RESEARCH PROJECTS. **DR AGUEDA GRAS-VELAZQUEZ**, SCIENCE PROGRAMME MANAGER AND HEAD OF THE SCIENCE EDUCATION DEPARTMENT AT EUROPEAN SCHOOLNET, EXPLAINS

WHY WAS SCIENTIX SET UP? WHAT ISSUE IS IT HOPING TO ADDRESS?

Scientix was originally set up to ensure that all STEM materials (lesson plans, activities, publications, etc.) created through publicly-funded projects (e.g. financed by the European Commission) had a "home" once the projects and their funding ended – and to provide people with access to these materials beyond those directly involved in each project. Since then, however, it has become a catalyser for collaboration and exchange among all those working to improve STEM education, while still providing a repository of resources from EU-funded projects.

Some people in STEM education find themselves working in isolation and this is an issue we hope to address. Working alone can become demoralising and isn't always efficient because people end up reproducing resources that have already been created, some of which may not work. We're addressing this by giving people working in STEM education an opportunity to connect to and learn from others, and work more efficiently to improve STEM education overall.

WHO IS SCIENTIX AIMED AT?

Primary and secondary school teachers, policy makers, researchers, teacher trainers – pretty much anybody interested in STEM education. The focus was originally on science teachers, but we now know that Scientix is being used by teachers of other subject areas, such as language teachers, who want to discuss different topics and have access to interesting learning materials for their classes!

WHAT RESOURCES DOES SCIENTIX PROVIDE FOR EDUCATORS?

We provide free access to all of the materials created by publicly-funded STEM projects, training, exchange opportunities, research, news via newsletters and social media. The training can be done online via webinars, MOOCs, or face-to-face via workshops in the European Schoolnet's (EUN) Future Classroom Lab in Brussels and as part of other EUN- or nationally-organised events. The exchange opportunities happen via live events, seminars, workshops and conferences.

HOW MANY TEACHERS/SCHOOLS ARE ENGAGING WITH SCIENTIX ACROSS EUROPE?

At the moment, over 8,000 different teachers connect with Scientix every month, which means that over 100,000 primary and secondary students are reaping the benefits of Scientix on a monthly basis! By engaging with Scientix, teachers and schools can learn from others, and get anything they need for their STEM classes.

THERE ARE SCIENTIX NATIONAL CONTACT POINTS (NCPS) FOR TEACHERS IN EUROPE. WHAT IS THEIR ROLE AND WHAT RESOURCES OR SUPPORT CAN THEY OFFER?

Their role is to act as a link between Scientix at a European level and activities taking place in each country. NCPs engage with national communities of STEM professionals, publicise Scientix activities, provide information and exchange opportunities, and organise

Working with Lego at the Scientix 5th Science Projects Workshop, Future Classroom Lab

ABOUT DR AGUEDA GRAS-VELAZQUEZ

"As Head of the Science Education Department at European Schoolnet (EUN), I oversee the coordination of all the mathematics and science projects in which EUN is involved: that is, assigning the appropriate project manager and colleagues to work on each project, reviewing the activities, providing guidance and ensuring they all work together to improve STEM education."

ABOUT SCIENTIX

Scientix is a free-to-access community for science education in Europe, funded by the European Union's Research and Innovation Directorate. It promotes and supports a European and worldwide collaboration among STEM teachers, education researchers, policymakers and other STEM education professionals.

www.scientix.eu

national workshops, webinars and other related activities, depending on the needs of the country in terms of STEM education.

NCPs also monitor and analyse national initiatives regarding science education policy and practice, providing an overview of the national initiatives in science education taking place across Europe. These reports are published on the Scientix website. In the main, NCPs are Ministries of Education, but, in some cases, they are teacher training institutions, universities or teacher organisations that are best placed to support STEM education in the relevant countries.

WILL UK SCHOOLS AND TEACHERS STILL BE ABLE TO ACCESS EUN RESOURCES AFTER BREXIT?

UK schools and teachers will continue to be welcome to access the resources and online activities and training, like all other teachers and schools worldwide. The only limitation would be that we would not be able to cover the costs of flights and hotels for UK teachers to attend EUN events, and this applies to all teachers outside of the EU.

SCIENTIX IS COMING TO THE END OF ITS HORIZON 2020 FUNDING PERIOD. WHAT'S NEXT FOR THIS PROJECT?

We understand that there will be funding in 2020 for an additional three years. We appreciate the European Commission's General Directorate for Research and Innovation for the funding so far and its continuous support.

FINALLY, WHY ARE YOU PASSIONATE ABOUT SCIENCE EDUCATION?

Science helps explain the world and improves our lives – and the possibilities it provides from the nuclear level to the cosmological horizon are fascinating. Science is everywhere: in the breakfast we eat in the morning, the clothes we wear, the transport we use to go to school or work, the TV we watch in the evening, the games we play, the medicines we take when we're unwell, everything. We should all understand its importance and ensure science helps us even more in the future by encouraging eager students, supporting governments and creating a committed society.

Through science education, Scientix is working to ensure that some students follow science careers, but, more importantly, we're ensuring that all students, regardless of what they end up studying in the future, understand the importance of science in their lives.

THE NEED FOR ANTIMICROBIAL PEPTIDES IN A WORLD OF ANTIBIOTIC RESISTANCE

TERRI CAMESANO IS A PROFESSOR OF CHEMICAL ENGINEERING AT WORCESTER POLYTECHNIC INSTITUTE IN THE US. MUCH OF HER RESEARCH IS CONCERNED WITH PEPTIDES, SPECIFICALLY THEIR ANTIMICROBIAL AND WOUND HEALING PROPERTIES. HER FINDINGS COULD LEAD TO THE DEVELOPMENT OF STRATEGIES TO TREAT BACTERIAL INFECTIONS

IMAGINE THIS

Alexander Fleming's discovery of penicillin was, in many respects, extremely fortunate. Before leaving for a two-week holiday, Fleming left a petri dish containing a *staphylococcus* (a type of bacteria) culture on a lab bench by accident (it was supposed to be placed inside an incubator).

Somehow, a *Penicillium* mould spore was accidentally introduced – most likely by floating up a stairwell from the laboratory below – and upon his return from holiday, Fleming noticed that there was a bacteria-free zone in the petri dish, which inhibited the growth of *staphylococci*. This newly discovered active substance was effective even when diluted up to 800 times. He named it penicillin.

As Fleming later noted, "One sometimes finds what one is not looking for."

Antibiotics are a type of antimicrobial substance that is active against bacteria and is a vital means of fighting bacterial infections. It is difficult to overstate the importance of antibiotics in terms of treating a variety of conditions. Indeed, it is no exaggeration to say that antibiotics revolutionised medicine in the 20th century, particularly with Alexander Fleming's discovery of penicillin in 1928. It would be impossible to calculate just how many lives have been saved by this important discovery.

However, the effectiveness of and easy access to antibiotics has led to their overuse and some bacteria have developed resistance. This is a major problem, with the World Health Organization saying that antibiotic resistance is one of the biggest threats to global health, food security, and development today. As a result, the world needs to quickly change the way it prescribes and uses antibiotics to limit the spread of antibiotic resistance.

Researchers around the world are investigating new methods of treating infections and other illnesses, ones that will reduce our reliance on antibiotics in the future. Terri Camesano is a professor of chemical engineering at Worcester Polytechnic Institute in the US. Much of her research is focused on antimicrobial peptides, which have a lot of potential to help people when they are developed into therapeutic treatments.

WHAT ARE ANTIMICROBIAL PEPTIDES?

Antimicrobial peptides are a class of natural molecules that are used by all types of single cell and multicellular organisms. Some of the ones that Terri and her group have worked with come from humans, fish, sheep, and even pigs, and they are part of their immune systems. They have the ability to kill fungi, viruses, bacteria, yeasts, and cancer cells. "I'm interested in them because they have unique antimicrobial properties," she explains. "For one thing, it is very difficult for humans to develop a resistance to antimicrobial peptides."

WHAT APPLICATIONS COULD THEY HAVE IN THE BIOMEDICAL AREA?

Antimicrobial peptides have great potential to be used to develop new antimicrobial and anti-infection treatments and therapies. Terri believes they will be especially important in developing strategies to treat bacterial infections that are resistant to our current group of antibiotics. Her team is also looking at whether antimicrobial peptides can be made into a coating that will be placed on biomedical devices, such as catheters or orthopaedic implants. This will help prevent many hospital-associated infections.

TERRI CAMESANO

Professor of Chemical Engineering and
Dean of Graduate Studies
Worcester Polytechnic Institute, USA

FIELD OF RESEARCH

Chemical Engineering

RESEARCH PROJECT

Terri is investigating the use of antimicrobial peptides for the treatment of infections and wounds. One of her current focuses is on finding an effective means to deliver the antimicrobial peptides, which would reduce our reliance on antibiotics.

FUNDER

National Science Foundation

DO PEPTIDES HAVE ADVANTAGES OVER OTHER ANTIMICROBIALS?

Yes! The advantages of creating a peptide-based therapy are that they are already naturally occurring - all types of living cells and organisms have them. Antimicrobial peptides are produced in many types of animals and cells, ranging from insects, to giraffes, to humans. They also will be safer and less toxic than many alternatives and are very broad-acting, i.e., they can kill many types of bacteria and viruses.

HOW DO THEY WORK?

Peptides work with a very interesting mechanism, which is more physical in nature. All cells, whether they are in a bacterium or a human, have membranes that encase them and protect the internal components. The antimicrobial peptide works on the bacterial cell membrane. It can sometimes form pores and, in other cases, allow pieces of the membrane to break off. This causes the bacterium to die.

DO PEPTIDES HAVE ANY OTHER EFFECTS?

Some of the antimicrobial peptides have other helpful effects to the body. "One human peptide we work with quite a bit is LL37," says Terri. "This peptide can also help the body heal from wounds by promoting a positive immune response and decreasing inflammation."

HOW WILL THE ANTIMICROBIAL PEPTIDES BE DELIVERED TO THE SITE OF A POTENTIAL INFECTION OR WOUND?

This is the part of the technology Terri and her group are currently working on. One of the current strategies is to bind the antimicrobial peptide to another human protein, such as collagen. Collagen can form a scaffold, or support, which will hold the antimicrobial peptides in place and allow the wound healing and antimicrobial activities to take place.

If this can be achieved, our reliance on antibiotics will likely diminish and the team's work will go some way to resolving the significant issues we face regarding antibiotic resistance. There is still some way to go, but research like Terri's is paving the way for a new era in treating infections and wounds.

ABOUT CHEMICAL ENGINEERING

Chemical engineering is applied chemistry. This branch of engineering is focused on the development of chemicals and the manufacture of products using chemical processes. This might include the designing of equipment and processes, through to the mixing and processing of chemicals to create products with a wide range of benefits.

Given this broad definition, chemical engineers generally need a broad skill set. They might apply the principles of chemistry, biology, physics, and mathematics to solve problems associated with the production or use of chemicals, fuel, drugs, and even food.

WHAT CAREER ROUTES ARE AVAILABLE WITH A CHEMICAL ENGINEERING DEGREE?

"I loved chemical engineering as an undergraduate major because it is so versatile. Graduates can go into many different fields, ranging from energy and environment to biotech, pharmaceuticals, petrochemicals, materials, and more," says Terri. "I also think the skills that we teach chemical engineers translate into many non-technical areas, as well. We learn to solve problems, work in teams, stick to a budget, and communicate."

There are many possibilities and opportunities with a chemical engineering degree. While there are traditional paths, it can be used to do other things as well. If you really want to be a professor or start a business, you can do that! There are chemical engineers who have gone on to leadership roles in all types of industrial, academic, and government settings.

WHAT SUBJECTS AND EXTRACURRICULAR ACTIVITIES SHOULD YOU TAKE AT SCHOOL IF YOU ARE INTERESTED IN STUDYING CHEMICAL ENGINEERING?

"I would encourage any student studying engineering to take on some extracurricular activities that are complementary to their studies," explains Terri. "If you love photography, you can be an officer in the yearbook club or school newspaper. Having a chance to be in a leadership role in a club is also really good experience and will help you in your future career in engineering."

Students and engineers also often spend a lot of time sitting down, so it is important that you indulge in some physical activity, such as dancing or playing a sport, to keep you fit and healthy. Terri encourages everyone to study mathematics if they can and likes to remind her students that you do not have to be the best at any particular subject, and you do not have to be a "natural" at maths or science in order to become an engineer - the most important qualities are passion and a willingness to work hard.

ISN'T ENGINEERING FOR BOYS? WHY SHOULD MORE GIRLS STUDY CHEMICAL ENGINEERING?

"I truly believe that engineering is for everyone who wants to solve problems and make a difference in the world," says Terri. "In the US, about 18-20% of engineers are women. That number is steadily growing as more women rise up in the workplace. When I was first starting out, there were a lot fewer women in my field. However, I didn't let that stop me and stayed focused on my goals, while always seeking out mentors (men and women) who could help me."

Peer mentors are also really helpful. Early in Terri's career, she would meet regularly with a group of other assistant professors to share the challenges and triumphs of starting their independent careers.

OPPORTUNITIES IN CHEMICAL ENGINEERING

- A chemical engineer can earn between $51,710 and $66,286 with less than a year's experience. This can rise to more than $120,000 after 20 years' experience.
- ThoughtCo. has dedicated a webpage to explaining some of the top reasons to study engineering, including the fact that engineers are happy and make a difference!

  https://www.thoughtco.com/why-study-engineering-604017
- There are chemical engineering internships across the US in a wide variety of sectors, many of which are professional development programmes.

  https://graduateland.com/s/chemical-engineering-internships/united-states

Terri in her lab with her research group of students.

ASK PROF TERRI CAMESANO

WHAT WERE YOU LIKE AT SCHOOL?

In high school, I always worked hard to learn and achieved high grades. I was also a cheerleader and loved to dance. I grew up in a small town and neither of my parents went to college. I struggled when I first went to college because I didn't feel as prepared as some of my peers. It took many years for me to gain confidence in myself. I would say that my Master's degree experience was the most transformative for me. I went from being a shy student, who never reached out, to someone who was always participating in class and always engaged.

I felt a real sense of pride when I finished my Master's thesis, and then my PhD was relatively easy because I was very sure of myself and very focused. My education also helped me to go out and explore the world. Since I grew up travelling very little, I was thrilled to be able to travel to national and international conferences to talk about my research and meet peers.

WHEN DID YOU DECIDE YOU WANTED TO BE A CHEMICAL ENGINEER?

I didn't know anything about engineering when I went to college. I was encouraged to go into medicine because that is where a lot of smart students are directed. I planned to major in chemistry and go to medical school. But one of my chemistry professors in my freshman year told me about chemical engineering and suggested that there would be more opportunities, and that it was going to be a great fit for me. I am so glad that I had the guidance of that professor, because I can't imagine being anywhere else.

WHAT DO YOU THINK IS YOUR GREATEST ACHIEVEMENT TO DATE?

In my personal life, I am raising three intelligent, kind, and wonderful daughters, and that is what I am most proud of in life! Professionally, I feel very proud to be a mentor and an advocate for students. I am amazed at how much they can grow and learn, and I am honoured to be a part of their journey.

EDUCATING YOUTH ABOUT BIOSECURITY CAN HELP PREVENT THE SPREAD OF DISEASE IN FARM ANIMALS

SCIENTISTS WORKING ON THE **ANIMAL DISEASE BIOSECURITY COORDINATED AGRICULTURAL PROJECT** ARE INVESTIGATING BIOSECURITY MEASURES DESIGNED TO REDUCE THE SPREAD OF DISEASES AND PESTS IN LIVESTOCK. SO, WHY ARE THE PROJECT'S TEAM MEMBERS ALSO FOCUSED ON EDUCATING YOUNG PEOPLE?

In an agricultural system, biosecurity refers to what is being done to keep harmful biological agents, such as viruses, bacteria, fungi, parasites and other microbes, from entering or spreading within that system. Farm managers and owners of livestock all practise biosecurity to some extent, whether they are aware of it or not. This is because biosecurity measures can be as simple as keeping sheep fenced off from neighbouring sheep.

Whether a farmer has one sheep or 101 sheep, he or she has to follow biosecurity practices to avoid spreading disease. This means that appropriate policies and incentives – from the farm-level to governmental levels – are needed to reduce the impact of diseases in livestock animals, including dairy and beef cows, horses, pigs, sheep, goats, llamas, alpacas and poultry. It is also important to ensure everyone receives the message in an actionable way.

The aim of the Animal Disease Biosecurity Coordinated Agricultural Project (ADBCAP) is to help develop and instil these much-needed biosecurity protocols and policies in animal agriculture. And the 20-strong team, based at universities all over the United States, has expertise in animal science, veterinary medicine, agricultural economics, public policy, risk communication and education.

WHY SHOULD YOUNG PEOPLE BE EDUCATED ABOUT BIOSECURITY?

By educating the next generation of agricultural producers on biosecurity, protecting animal health becomes a routine life skill. Having an informed and engaged agricultural community can help mitigate risk from endemic (commonly found) and emerging disease-causing agents, which, in turn, creates safer and more profitable agricultural practices. For example, some diseases can only be prevented through biosecurity because there are no known treatments or vaccines. African swine fever and bovine spongiform encephalopathy (BSE) are two examples of such diseases.

"We were encouraged by the success of past public health campaigns (such as those against smoking, or promoting the wearing of seatbelts and bike helmets) that were aimed at children and, through them, spread to adults," says Jeannette McDonald, the ADBCAP's education lead and Director of TLC Projects, LLC. "We are hoping to see 'trickle up' education, from the 6th-12th graders to parents and other adults within their sphere of influence, as well as through active biosecurity advocacy within their communities."

HOW ARE ADBCAP MATERIALS REACHING YOUNG PEOPLE?

Many of ADBCAP's outreach team actively engage with 4-H (a national youth development programme located in the United States), the National FFA Organization (a US organisation providing leadership opportunities and experiential learning for students in high school agriculture programmes), and through agricultural extension programmes, which provide non-formal learning and research-based educational activities to agricultural communities around the country. However, as Jeannette explains, they also visit schools, agricultural events and other venues that provide opportunities to discuss biosecurity.

Currently, the team offers modules in animal biosecurity risks and strategies, infection and disease transmission, and is developing further

modules to train young people to become biosecurity advocates in their communities. For example, helping to spread the word about these biosecurity risks and strategies would make you a biosecurity advocate.

An accompanying Teacher's Guide (still under development) will include activities and materials to support and extend these modules. In addition, the outreach team has developed a complementary programme of hands-on activities to reinforce the lessons in the modules, called SCRUB (Science Creates Real Understanding of Biosecurity).

WHAT HAS BEEN THE OUTCOME OF THESE OUTREACH ACTIVITIES?

ADBCAP has been going for four years, and the team's education and outreach activities are in the final stages of development. In this short timescale, some positive outcomes have already been identified: "We have pilot data that suggests changes in awareness of the importance of biosecurity in general," says Jeannette, "and an increase in understanding and acknowledgement of the importance of hand washing and changing footwear, specifically." Agricultural teachers participating in preliminary SCRUB laboratory testing/evaluation activities in Massachusetts and Oklahoma have also responded positively.

This is certainly a step in the right direction. By instilling a good understanding of and enthusiasm for biosecurity in both educators and youth, the ADBCAP team is laying the foundation for improving animal welfare, reducing the spread of animal diseases and protecting farmers' livelihoods for the next generation.

JULIA M. SMITH, DVM, PHD

ADBCAP Project Director and Research Associate Professor
University of Vermont, USA

FIELD

Animal and Veterinary Sciences

EDUCATION PROJECT

Members of the ADBCAP education team are developing online modules to teach young people in 6th-12th grades about biosecurity. Their aim is to train the next generation of livestock producers to become advocates and practitioners of improved biosecurity practices.

FUNDER

National Institute of Food and Agriculture

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Dr Rankin teaching at the International Livestock Inspectors Association in Fargo, North Dakota in 2015

ABOUT BIOSECURITY

Biosecurity is a wide field, encompassing many different disciplines. Broadly, it can be described as a set of procedures designed to protect the health of humans, animals and plants. These biosecurity procedures range from containment strategies for disease outbreaks, to safe and secure housing and sharing knowledge and skills, which lead to proactive human behaviours in disease prevention through responsible animal management.

WHY DO WE NEED TO TAKE BIOSECURITY SERIOUSLY?

Any industry involving animals depends on biosecurity. An animal breeder who takes in a sick animal without quarantine could infect the whole herd. Professional horse trainers whose students allow their show horses to drink out of a common water trough at a show put their animals at risk. A veterinarian travelling between barns, not using proper biosecurity protocols, could transmit disease.

Good biosecurity practices promote animal welfare in all aspects of the animal's life. An animal's risk of disease or health problems can be reduced dramatically by providing suitable vaccinations and appropriate, timely veterinary care, as well as controlling interactions with other, potentially infectious animals. An animal's quality of life can also be improved by making sure they have comfortable, safe housing; that their environmental needs are met; and that they experience no unnecessary stress.

Good biosecurity protocols also benefit humans, from both a health and economic perspective. They benefit farmers by reducing risks to animals' health, which directly affects food production and farm profitability. By controlling animal diseases, biosecurity also keeps domestic and international trade channels open, enables low food prices, and promotes consumer confidence in food safety and wholesomeness. Lastly, some diseases carried by farm animals are zoonotic, meaning they can be transmitted between animals and humans, sometimes with more serious effects. Avian flu is one example of a zoonotic disease. Strong biosecurity protocols therefore protect animals, the economy, the environment and humans.

HOW DO YOU TRAIN FOR A JOB IN BIOSECURITY?

Because biosecurity is such a broad field, it offers many career options. Some people working in biosecurity have backgrounds in veterinary medicine and/or animal science, which equips them to consider the animals' medical needs as well as develop plans with farmers and local governments for protecting animal health. Others have a broader biological background, approaching biosecurity from the perspective of animal behaviour, genetics or patterns of disease transmission. Educators and communicators play a vital role in biosecurity, too, offering training and education in best practises. The huge array of products involved in animal care mean that those with an interest in manufacturing or marketing also have a role to play. It is a field in which a range of interests and strengths can be used to make positive changes for humans and animals.

OPPORTUNITIES IN BIOSECURITY

- Websites such as FutureLearn and Coursera have free courses on different aspects of biosecurity, from disease control to animal welfare.

- Veterinary practice involves biosecurity daily. Biosecurity is also a concern of federal and state veterinarians (known as public-sector veterinarians in the UK and district veterinarians elsewhere), biosecurity officers located at border control and in quarantine facilities, farm managers and research scientists.

- If you qualify in veterinary medicine in the US, you can apply for the Veterinary Medicine Loan Repayment Program, which will repay a portion of your student debt in exchange for spending three years working in an area suffering from a shortage of veterinary care and participating in outreach and education programmes for food animal producers.

- Given the huge range of roles and opportunities in biosecurity, salaries vary.

TOP TIPS

01 – Get out and experience different fields and careers. Find something you are passionate about and then pursue it. If you love what you do, it won't feel like work. – ***Jeannette***

02 – Find people that inspire you to do more, and be a positive influence. – ***Jeanne***

03 - Strive to become an engaged learner, and get as many diverse experiences as you can. – ***Susan***

04 - You can contribute to biosecurity in a range of ways; it's a field that needs lots of different skillsets and interests. – ***Betsy***

MEET FOUR MEMBERS OF THE ADBCAP EDUCATION TEAM

JEANNETTE MCDONALD, DVM, PHD, *Professor Emerita, University of Wisconsin-Madison, and CEO and Executive Director of TLC Projects, LLC*

I'm the lead for the education team, which creates online education products. This means I organise the work of the team, guide them in designing the modules and liaise with developers.

My bachelor's degree was in education, which I followed with a doctorate in veterinary medicine. After a time spent in veterinary research, I pursued a PhD in adult education, focusing on continuing professional education. I took the first online course offered at my university, and it hooked me on distance education: I've been a strong advocate ever since. Now I use my expertise in teaching online to teach about veterinary medical topics such as biosecurity. I love that my courses are available to anyone, anytime, anywhere.

We have a better chance changing attitudes and habits with our youth – our next generation of livestock producers – than with adults. Biosecurity is essential to the health of agricultural communities. These youths can change attitudes and habits now and in the future.

SUSAN KERR, DVM, PHD, *Professor Emerita and (retired) Livestock and Dairy Extension Specialist, Washington State University Extension*

I help develop educational online modules for those interested in learning about biosecurity in an enjoyable, engaging and memorable way.

I worked in mixed animal rural veterinary practice for seven years. It became increasingly frustrating to have the knowledge and skills to be able to help animals but hamstrung by owners' financial situations. I decided to focus more on the educational, preventative aspects of working with animals, so I entered graduate school to learn to teach effectively.

I can't think of a better way to address animal welfare than by preventing the pain, suffering, and death associated with diseases. By enacting biosecurity measures, owners ensure animals have clean food, water and housing, protection from predators and parasites, appropriate veterinary care and low-stress lives.

Good communication and teamwork skills are very important in these industries, along with a lifelong interest in learning. My advice to young people is to pay attention to aspects of your work that bring you the most joy and capture your attention most: Is it animal behaviour? Genetics? Direct animal care? We need people doing all these things, so there is a career for you with animals!

BETSY GREENE, PHD, *Professor and Equine Extension Specialist, School of Animal and Comparative Biomedical Sciences, University of Arizona*

I am creating the hands-on classroom activities (SCRUB kits) with Dr Kris Hiney (Oklahoma State University). These kits demonstrate and expand upon key concepts taught in our modules, and are designed to be used by instructors, educators and volunteers.

I began working at a stable in Massachusetts at the age of 11 for $20 a week and a riding lesson, learning all aspects of horse care. I also worked in a feed store warehouse. These experiences sparked my interest in an animal-related career. I completed a veterinary technology programme (support staff in a veterinary practise), and continued to completion of my doctoral degree, with research focused in equine muscle biology/exercise physiology. My career in teaching and extension education spans over 26 years and three universities.

If you are interested in working with animals there is a vast choice of options in career areas and education, depending whether your interests lie in the physical, intellectual or even psychological aspects of the industry. Careers can range from hands-on training, breeding and manufacturing products, to careers requiring advanced degrees such as research and veterinary sciences.

JEANNE RANKIN, DVM, *Associate Specialist in Animal Health, Animal Disaster and Agrosecurity, Montana State University Extension*

I'm a subject matter expert in biosecurity for the education team and a USDA Foreign Animal Disease Diagnostician (FADD).

I was raised on a cattle ranch and grain farm in Montana. I was an ambulatory veterinarian for 17 years before becoming Montana's assistant state veterinarian and acting state veterinarian. After six years, I became Montana State University Extension's programme lead for animal disaster, animal health and agrosecurity planning. I help local organisations create an agriculture disaster plan unique to their region. It seemed a great fit when I was asked to join the biosecurity education team, and it has been deeply rewarding.

Good biosecurity protocols decrease animals' pain and suffering, as well as death rates and treatment costs. Biosecurity strategies reduce risk to humans and animals, as many diseases can transfer between us. The basic animal biosecurity plan is easy and inexpensive to implement while dramatically reducing disease transmission.

There is not a more fulfilling life than caring for animals. Being outdoors working with nature and raising food for the world gives you self-satisfaction and self-worth.

TEN CAREERS THAT MATCH YOUR SKILLS AND PERSONALITY

MY CAREERS OPTIONS USES SOPHISTICATED PSYCHOMETRIC TESTING TO HELP YOU DISCOVER CAREERS THAT SUIT YOUR PERSONALITY, INTERESTS, PREFERENCES AND SKILLS. CHRISTOPHER MAURE, ONE OF MCO'S TWO DIRECTORS, EXPLAINS HOW THIS SIMPLE-TO-USE APP WORKS

ANYONE USING THE MY CAREERS OPTIONS (MCO) APP WILL COME AWAY WITH A PERSONALITY AND SKILLS ASSESSMENT AND A TOP10 REPORT. WHAT ARE THESE?

Users complete a set of easy puzzles, questions and quizzes, which can be taken anywhere, anytime and on any device. Then, the app's clever selective algorithm analyses the user's answers to scientifically and objectively determine their skills, abilities, personality traits, interests and preferences for real-life careers. This is the basis of the MCO assessment.

From this assessment, a Top10 Report is automatically generated, which shows the user ten careers that best suit their personality, skills and preferences, regardless of their IQ or social status. The report also includes information on salaries, working times and conditions, routes into the industry, what you'll be doing every day, and how to advance in the career.

HOW ACCURATE IS THE MCO'S PERSONALITY AND SKILLS ASSESSMENT?

MCO uses a selective algorithm to produce a profile of the individual's unique skills and personality. It's based on some of the most highly respected assessments currently available, using tried and tested technology and then mixing it up with our own assessment methods and ideas. We also draw on the considerable skills of Dr David Stillwell and his team at The Psychometrics Centre, as well as developers from around the world.

> *"The most entertaining job in the world is no fun if it isn't what you want to do or are good at"*

WHY ARE PERSONALITY TRAITS SO IMPORTANT WHEN DECIDING ON A CAREER PATH?

Personality is the best indicator of what you would most like to do, and what you would be most comfortable and motivated doing. The key to a happy career is matching your personality and preferences with your skills. We put more emphasis on personality and preferences because it's often possible to up-skill someone into a role but it's impossible to force someone to like that role, be fulfilled and give of their best.

NOWADAYS, PEOPLE RARELY STAY IN THE SAME JOB OR PROFESSION, EVEN. HOW DOES MCO ACCOUNT FOR THIS?

We're not experts in recruitment but we've definitely observed what we call "square peg syndrome". Young people are often taken down a particular career path for reasons that have nothing to do with their preferences or skills. This can happen for many reasons: financial, social circumstances, family expectations, etc. but this leads to young people being unhappy with their career choice.

ABOUT CHRISTOPHER MAURE

"I'm the technologist primarily responsible for the development of the MCO assessments along with our partners at the University of Cambridge Psychometrics Centre. I also take care of the branding and image of MCO."

ABOUT MY CAREERS OPTIONS

My Careers Options is an online careers matching app, developed with the University of Cambridge Psychometrics Centre and Careers England. Currently aimed at young people aged between 11 and 19 years, the app will soon be available to those aged between 20 and 30 years.

www.mycareersoptions.co.uk

There are many more opportunities these days for people to change careers, but this is expensive for the employer and a waste of time for employees. What would be better is if they were in the right career from the start. It's true that people change and are more open to career shifting now than they've ever been in the past (our Careers Changer tool, which we'll release next year, will help with that), but, fundamentally, if we can reduce that "churn" by setting people off on their best career path to start with, then that has to be of great help to employers and employees alike.

WHO IS MCO AIMED AT?

It's initially aimed at students aged between 11 and 19. We hope to make a massive difference in this age group because most students don't have a clue about what they want to do in life. There's a whole wide, weird, wonderful world of work out there to be explored and MCO will be the first portal to this universe of endless opportunity.

CAN MCO BE USED ANYWHERE IN THE WORLD?

We're based in the UK but MCO is ripe for the international market, particularly English-speaking countries. We're developing a product for the US market right now and are also in talks with educational bodies in India and Pakistan. Our aim to make the assessment multilingual.

FINALLY, WHAT'S YOUR ADVICE TO YOUNG PEOPLE?

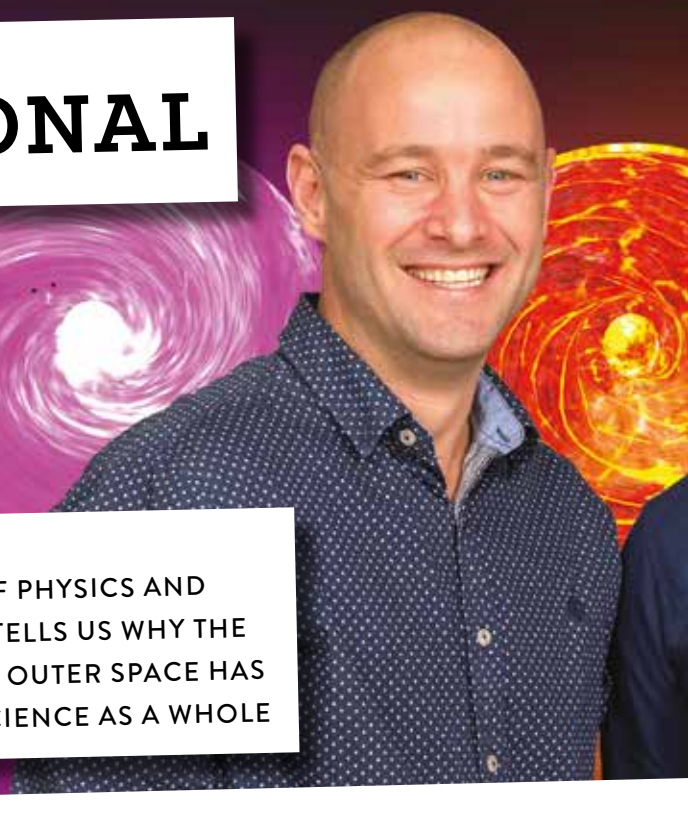
Obviously, my advice is to complete the My Careers Options assessment before making any important decisions! Seriously, though, young people are bombarded from all angles with options, choices and decisions. My advice is: make sure you cut through the noise and be logical about the decisions you make, which could easily mean following your heart not your head.

The most entertaining job in the world is no fun if it isn't what you want to do or are good at. Pick something that you like and make sure you know why you like it and why you could be better at it and enjoy it more. It's important to remember that there are hundreds and thousands of opportunities out there that you may never have considered. We've found the Top10 Report often comes up with jobs people would never have thought they could do or jobs they've never even heard of. It's got to be good if you're able access a pool of potential careers by exploring all the opportunities open to you, and armed with a real understanding of where you, as a unique individual, could fit within those opportunities.

THE MCO ASSESSMENT AND TOP10 REPORT COSTS £47.00. FOR A 50% DISCOUNT USE THIS CODE: MCFUT120

INTERESTED IN A BULK LICENSE FOR YOUR SCHOOL OR ORGANISATION? CONTACT MCO:
www.mycareersoptions.co.uk/pages/contact-us

WHY GRAVITATIONAL WAVES ARE OF SUPERMASSIVE IMPORTANCE



DR PAUL LASKY, SENIOR LECTURER IN THE SCHOOL OF PHYSICS AND ASTRONOMY AT MONASH UNIVERSITY IN AUSTRALIA, TELLS US WHY THE RECENT DETECTION OF GRAVITATIONAL WAVES FROM OUTER SPACE HAS HAD SUCH A HUGE IMPACT ON HIS RESEARCH AND SCIENCE AS A WHOLE

(TRY TO) IMAGINE THIS

Gravitational astrophysicists are often interested in probing extreme regions of the universe. In this context, "extreme regions" refer to things such as black holes, which are impossible to fathom.

- Black holes are regions of extreme gravity in the universe. Light travels at around 300,000 km/s but, even at that speed, light cannot escape.
- Black hole collisions are some of the most energetic events in the universe. When the collision of two black holes was detected on September 14, 2015, approximately three solar masses of energy were released in less than one second.
- Earlier this year, the first ever picture of a black hole was captured. It is a supermassive black hole and lies in a galaxy called M87 more than 50 million light-years away.

Gravitational waves are tiny ripples in the fabric of space-time, which travel at the speed of light. Their existence was first proposed by Henri Poincaré in 1905 and then predicted by Albert Einstein in 1916, as a consequence of his general theory of relativity. However, in the 100 years since then, there was only indirect observational evidence for their existence, which came in the late 1980s. That was until February 2016, when the LIGO Scientific Collaboration announced the first detection of tiny ripples of space-time.

It is difficult to overstate just how important this discovery is; the detection of gravitational waves has opened a new window on the universe. Prior to this, scientists studied the universe through light waves. This includes radio waves, visible light, X rays and gamma rays. Every time an astronomer started looking at the universe through one of these lenses, new discoveries were made. Gravitational waves are no different.

Dr Paul Lasky, Senior Lecturer at the School of Physics and Astronomy, Monash University, is a member of LIGO and is interested in a number of topics under the broad heading of gravitational astrophysics (although he has a particular penchant for gravitational-wave astrophysics). The detection of gravitational waves has had an enormous impact on his research that is still felt to this day.

HOW WERE GRAVITATIONAL WAVES DETECTED?

Imagine two fixed points in space: As a gravitational wave passes between them, the physical distance between them changes – it grows and shrinks in oscillations. If you think of two perpendicular directions, while one direction grows, the other shrinks. Half a gravitational-wave cycle later, the opposite is true. The LIGO experiments exploit this fact to measure the difference in time it takes a pulse of a laser to travel in two directions perpendicular to one another.

"The LIGO experiment has four-kilometre long arms. The gravitational wave that we detected on September 14, 2015, caused those four-kilometre arms to change length by about one one-thousandth the size of a proton," explains Paul. "That is what LIGO detected with one of its experiments. Of course, many different things can cause such an instrument to wobble by such an amount. This is why two identical experiments were built; one in Livingston, Louisiana, and the other in Hanford, Washington (both in the US)."

The same signal was detected in both detectors with a difference in arrival time of just seven milliseconds. That difference is explained by the time it took the gravitational waves to pass from one detector to the next; they are separated by ~1,000 km.

WHAT DOES THIS DISCOVERY MEAN FOR ASTROPHYSICS, OUR PLANET AND OUR SOCIETY?

As well as helping to revolutionise our understanding of the universe, the discovery has enabled scientists to learn new things about phenomena such as black holes, extreme gravity, neutron stars, cosmology, gamma-ray

Paul and Greg Ashton (Associate Lecturer from the School of Physics and Astronomy at Monash University) stand in front of an artist's rendition of the interiors of neutron stars. Photo credit: Carl Knox, Swinburne University/OzGrav

DR PAUL LASKY

ARC Future Fellow and Senior Lecturer, Monash Centre for Astrophysics, School of Physics and Astronomy, Monash University, Australia

FIELD OF RESEARCH

Gravitational Astrophysics

RESEARCH PROJECT

Paul's research extends across a number of topics that can be filed under the broad heading of gravitational astrophysics. However, he has a particular penchant for gravitational-wave astrophysics.

FUNDERS

Australian Research Council (ARC), OzGrav: ARC Centre of Excellence for Gravitational Wave Discovery

bursts and stellar evolution. "While we've already learnt so much in just under four years of discovery, I think the future is even more exciting," says Paul. "We have spent years predicting different types of sources of gravitational waves that we hope to measure in the coming years and decades, but the most exciting discovery will be the one no one expects."

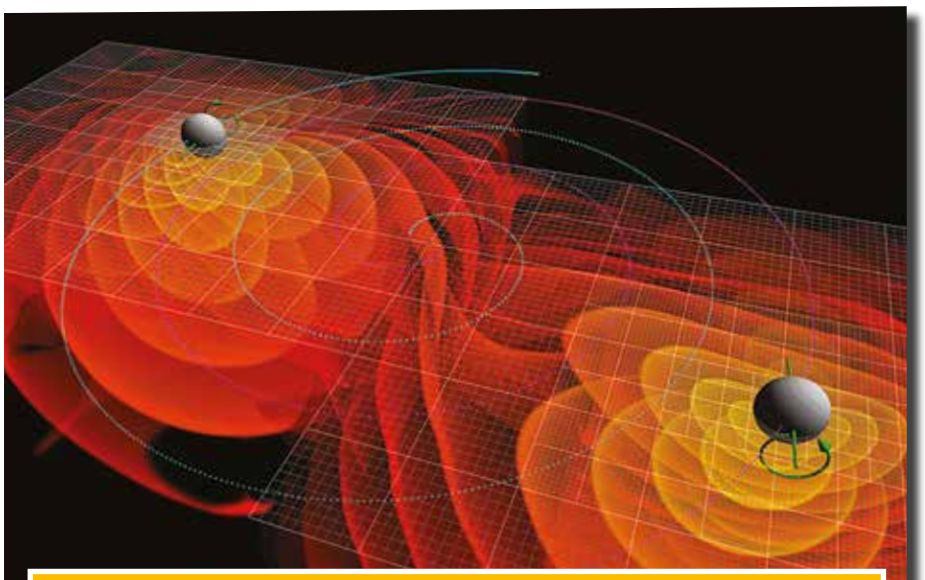
WHAT MIGHT WE LEARN ABOUT BLACK HOLES?

Paul is also a member of the Parkes Pulsar Timing Array, and this involves conducting research into the pulsar timing band. A Pulsar Timing Array (PTA) searches for signals on extremely long timescales. While the LIGO detectors can measure gravitational waves from colliding black holes that have similar masses to that of our Sun, those signals are only in the detector for between fractions of a second up to a few seconds.

PTAs search for signals on much longer timescales, which correspond to bigger (supermassive) black hole collisions.

Paul and his team are searching for these so-called supermassive black holes, which can be more than a billion times the mass of our Sun. Supermassive black holes are believed to reside in the cores of galaxies. The Event Horizon Telescope recently imaged a black hole in M87 – a 6.6 billion solar mass supermassive black hole in a nearby galaxy. "We know galaxies collide with one another, and we therefore expect the supermassive black holes to find one another, and eventually merge," explains Paul. "PTAs search for gravitational waves coming from the mergers of such supermassive black holes throughout the universe. At present, we have not seen anything, but the community is hopeful a positive detection is just around the corner."

The scientific community had to wait one hundred years for the first detection of gravitational waves – and that had a tremendous impact on our understanding of the universe – so waiting for the detection of gravitational waves from supermassive black holes shouldn't be a problem. Some things are just worth waiting for!



An artist's impression of merging black holes

WHAT IS GRAVITATIONAL-WAVE ASTRONOMY?

Gravitational-wave astronomy is a branch of gravitational astrophysics and observational astronomy, more broadly. Its aim is to collect information about objects in space that are an incomprehensible distance away from Earth. Because there is no possibility of ever travelling to the majority of objects being studied, researchers have to use the tools at their disposal, which have often been limited in scope.

The existence of gravitational waves – ripples in space-time – were predicted by Albert Einstein more than 100 years ago. In many ways, confirming the existence of them was seen as something of a "holy grail" for gravitational astrophysicists, not least because of the new opportunities it would afford researchers.

WHY ARE GRAVITATIONAL WAVES SO IMPORTANT TO GRAVITATIONAL ASTROPHYSICS?

Gravitational waves have two properties that are unique and of huge importance to researchers. First, there doesn't need to be any matter nearby for the waves to be generated by a binary system of uncharged black holes (which would emit no electromagnetic radiation). Second, gravitational waves can pass through any intervening matter without being significantly scattered.

If, for example, somebody is attempting to observe light from a distant star, this could be blocked out by interstellar dust, but gravitational waves will pass right through. Together, these two properties enable gravitational waves to carry information about astronomical phenomena that was previously unattainable.

ARE THERE ANY OPPORTUNITIES FOR CITIZEN SCIENCE WITHIN GRAVITATIONAL ASTROPHYSICS?

Yes. There is a citizen science opportunity called Gravity Spy, which is hosted by the Center for Interdisciplinary Exploration and Research in Astrophysics (CIERA), at Northwestern University in Illinois, USA.

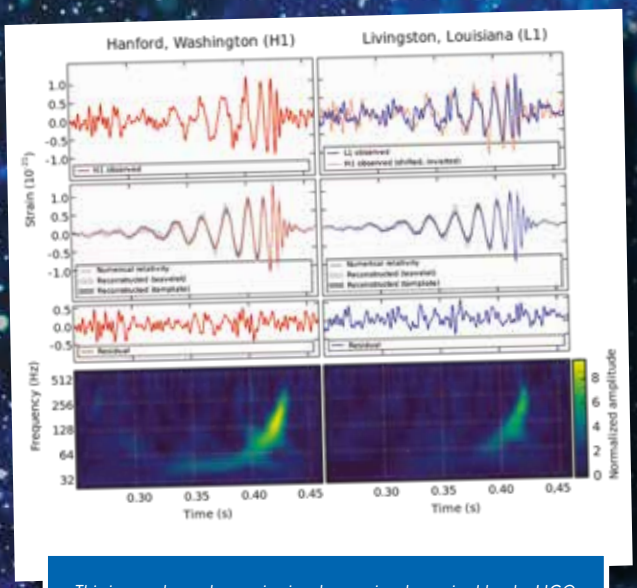
The idea behind the initiative is to pair citizen science with machine learning to help discover gravitational waves. In addition to characterising and eliminating the problem of noise (known as glitches) in detecting gravitational waves, Gravity Spy also promotes gravitational-wave sciences and involves the general public in the scientific progress made.

WHY SHOULD YOUNG PEOPLE TAKE AN INTEREST IN GRAVITATIONAL WAVES?

Gravitational waves are providing a completely new avenue for looking at and understanding the universe around us. Only a handful of times in the history of modern science have completely new ways to study the universe been unearthed. In just four years since the first detection, this field has already started to revolutionise our understanding of aspects of the cosmos. The near future is sure to hold exciting new discoveries as well.

OPPORTUNITIES IN ASTRONOMY

- According to PayScale, an average salary for an astrophysicist in Australia is $91,000.
- However, Australia's Science Channel points out that the space industry "generates a lot of employment for engineers, mathematicians, physicists, chemists, biologists, doctors – even lawyers who are devising a regulatory regime covering all of our activities in space".
- Finding work experience in astronomy is one of the best ways of discovering whether a career in this field is for you. Many institutes in Australia offer work experience placements for high school students. Simply type in "astronomy work experience" in a search engine and you'll be presented with a long list!
- The Astronomical Society of Australia and Australian Space Agency have lots of resources to help you further your interest in space, including links to local amateur astronomical societies, fact sheets and summer vacation scholarships for university students.



This image shows the gravitational wave signals received by the LIGO instruments at Hanford, Washington (left) and Livingston, Louisiana (right), and comparisons of these signals to the signals expected due to a black hole merger event.

Find this article and accompanying activity sheet at https://futurumcareers.com/why-gravitational-waves-are-of-supermassive-importance

ASK DR PAUL LASKY

WHO OR WHAT DREW YOU TO ASTROPHYSICS IN THE FIRST PLACE?

There have been a number of influences for me. When I was a teenager, my dad read popular science books from people like Kip Thorne, Stephen Hawking, Paul Davies, etc., and I started following his lead. My dad is not a scientist, but he has one of the best analytic brains I have come across and he was able to digest the content of these books with relative ease. This is something that always impressed me; I don't have my father's mind, but this didn't stop me being absolutely fascinated by everything I read in those books.

At high school I had a couple of science teachers that really inspired me. I remember one chemistry lesson in the final years of high school – our teacher walked in, threw the standard curriculum on the floor, and decided to teach us all about quantum mechanics. I was awestruck about the non-deterministic nature of the universe. Probably more importantly, from reading popular science books, I became fascinated by the fact that giants in the field, including people like Einstein, were also unable to comprehend these aspects of the universe. There was – and still is – so much left to discover.

WHAT IS IT ABOUT YOUR RESEARCH THAT FASCINATES YOU?

I love uncovering new things about the universe. I love knowing that, for short periods of time at least, you're one of the only people on Earth who understands a certain phenomenon or a certain fact about the universe. I think any field of science would give people this thrill.

In terms of astrophysics research, I love furthering my understanding of extreme aspects of the universe. I cannot fathom the size, mass, density and temperature of any of the objects that I study, but that doesn't mean I can't understand the way they work! It also doesn't mean I can't make predictions for what we should see when we observe them with telescopes or gravitational-wave detectors, and then I actually get a chance to test those predictions and see if we, as a community, were right.

I love my job in general. I still have to pinch myself that I get paid to pursue my hobby. If I don't find a topic interesting, I don't work on it. I get to work with incredibly bright and motivated young people who have the world at their feet. I get to mentor them and help them pursue their dream of making contributions at the bleeding edge of science.

WOULD YOU LIKE TO TRAVEL IN SPACE?

Absolutely. I'm fascinated by how gravity works in general and would be amazed to understand the way it affects our daily lives in ways that we don't even realise. Going into space would give me another appreciation of this.

WHAT ADVICE DO YOU HAVE FOR YOUNG PEOPLE WHO ARE UNCERTAIN ABOUT WHAT TO DO WITH THEIR LIVES?

Follow your passion. I never knew that I wanted a career in astronomy or physics. I always loved learning about the universe but didn't realise it was something that I would be capable of doing as a long-term career. It was only through following my interest and passion that I was able to forge a career in this field, and now I rarely feel like I'm working. Instead, I truly feel like I'm getting paid to pursue my hobby.

Many people ask me why they should study physics or astronomy and what the job prospects are, but I think this is the wrong question. If you work hard, the jobs will come; passionate people with a solid scientific education are eminently employable in a whole range of fields. You'll never have trouble finding an excellent, well-paid job with a good science degree. But you'll also never get a better opportunity to scratch that itch and learn the fundamentals of the universe and its inner workings.

PAUL'S TOP TIPS

1. If you are interested in the field of gravitational astrophysics, you should get a good grounding in both physics and mathematics. However, there are other ways of getting into the field, such as with computer science or electrical engineering backgrounds; these can prove extremely valuable for creating software and mathematical/data-analysis techniques for understanding the complicated data.

2. Attaining a degree is not necessarily the only route into the field. If you have an interest in getting involved in the outreach and science communication side of the field, then there are opportunities out there.

3. Do not study physics or astronomy if the only thing you want is a job at the end of it. You should study these subjects because you are passionate about understanding how the universe works; we are only ever limited by our current understanding of the way things are, so contributing to the development of new ways of looking at the universe can shape the future.

GrEAT POTENTIAL: WHY CHINA AND THE UK ARE WORKING TOGETHER IN GRAVITATIONAL-WAVE RESEARCH

THE GRAVITATIONAL-WAVE EXCELLENCE THROUGH ALLIANCE TRAINING (GrEAT) NETWORK IS BRINGING SCIENTISTS IN THE UK AND CHINA TOGETHER, AND THEIR COLLABORATION IS OPENING A NEW WINDOW ON THE UNIVERSE

The Theory of General Relativity, proposed by Albert Einstein, was published in its final form in 1915. The ideas contained within it transformed many branches of science, including theoretical physics and astronomy, and moved away from many of the ideas primarily created by Isaac Newton. One of Einstein's theories claims we exist within the medium of space-time and that gravitational attraction is the result of a curvature in space-time, owing to the presence of mass.

His ideas regarding relativity and gravitation led to predictions that have since been shown to be accurate. One of the most well-known astronomical phenomena predicted by general relativity is the existence of gravitational waves, which is linked to the idea that when massive objects move rapidly (such as two black holes just before they collide), they will cause fluctuations (or "ripples") in space-time. We call these ripples gravitational waves.

Exactly 100 years after Einstein published his landmark theory, the LIGO Scientific Collaboration announced that it had succeeded in making the first ever direct gravitational-wave observation. Since then, interest in gravitational-wave research has grown, with researchers around the world dedicating more resources to the field. The Gravitational-wave Excellence through Alliance Training (GrEAT) Network is one example of this. It is funded by the Science and Technology Facilities Council UK with the aim of building links between the UK and China through gravitational-wave research, and brings together scientists from both countries and beyond.

The GrEAT Network is led by Ik Siong Heng, Professor at the School of Physics and Astronomy, University of Glasgow, and involves researchers from around the world, including Mariela Masso Reid, Xilong Fan, Laura Nuttall, Yan Wang, Jenne Driggers and Nils Andersson. The GrEAT Network has five main aims, which are to:

1. Identify potential industrial and commercial partners in China for gravitational-wave technology and expertise;
2. Provide high-quality training for early-career researchers on the planning and delivery of outreach (informing the public) on gravitational-wave astronomy;
3. Provide training on data analysis and numerical modelling that will have applications in gravitational-wave research and beyond;
4. Find people with the necessary skills to create, fabricate, install and innovate future gravitational-wave detector technologies;
5. In the UK, support and train PhD students and early career researchers, who are from Chinese institutions and working on space gravitational-wave detectors.

WHERE DO GRAVITATIONAL WAVES COME FROM?

All moving masses emit gravitational waves. However, the coupling between gravity and matter is extremely weak (one needs a massive object like the Earth to have significant gravitational attraction). So, the gravitational waves that researchers can detect with current technology come from compact and massive systems, such as merging black holes and neutron stars, within a relatively local portion of our universe (within about 1 billion light years).

WHY ARE GRAVITATIONAL WAVES OF INTEREST TO RESEARCHERS?

Gravitational waves are interesting because they are the ideal probe for the densest, darkest regions of our universe. Since gravity couples very weakly with matter, it is difficult to "block out" gravitational waves. Gravitational waves have already been used to directly observe black holes whizzing around each other and then colliding throughout our universe.

Furthermore, gravitational-wave observations from merging neutron stars provided researchers with a first glimpse into the central engine of gamma-ray bursts – one of the most energetic phenomena in the universe. "Gravitational waves have the potential to also reveal the physical processes deep within the core of exploding stars (supernovae) and tell us about the properties of matter within neutron stars," explains Siong. "Such matter is subjected to extreme pressure and temperature, which cannot be reproduced in a laboratory."

WHAT PRACTICAL OUTCOMES COULD RESEARCH INTO GRAVITATIONAL WAVES HAVE FOR SOCIETY OR INDUSTRY?

New technologies and instrumentation have been developed along the path to gravitational-wave detection. Many of these developments are starting to be used in industry, such as gravimeters (a device that measures tiny fluctuations in Earth's gravitational field, which can also be used to find oil and minerals), but also in healthcare, such as in stem cell research (which could revolutionise the treatment of many diseases and injuries).

WHY IS IT IMPORTANT FOR THE UK AND CHINA TO WORK TOGETHER ON THE GrEAT PROJECT?

The UK has been at the forefront of gravitational wave research for several decades with significant expertise and leadership in the international gravitational-wave community. Rapidly growing interest in gravitational-wave research in China, especially since the first gravitational-wave detection, provided an excellent opportunity for the two communities to collaborate and work towards exciting new avenues of research.

HOW IMPORTANT WAS THE FIRST DETECTION OF GRAVITATIONAL WAVES AND WHAT DID IT MEAN FOR THE FIELD?

Siong was one of the co-chairs of the collaboration team that made the first gravitational-wave detection in 2015. "I had just arrived in China for a family gathering when my email inbox exploded with messages about the discovery. It was a surreal experience, having spent decades in the field waiting for this moment and, when it finally happens, I was stuck in an internet cafe on the other side of the world trying to catch up!" he says. "The first detection was definitely a ground-breaking event. It marked the beginning of a new way of performing astronomy – gravitational-wave astronomy."

WHY SHOULD YOUNG PEOPLE CONSIDER A CAREER IN THE GRAVITATIONAL-WAVE FIELD?

The first detection of gravitational wave signals in 2015 was just the beginning. It opened a new window on the universe. There are many opportunities for new discoveries that will reveal the nature of our dark (gravitational) universe. If you want to become part of one of the most exciting scientific fields at present, then this is the field for you!

WHAT SORTS OF CAREERS ARE AVAILABLE IN THE AREA OF GRAVITATIONAL WAVES?

Most careers associated with gravitational-wave research would be academic. However, people working across many fields are required to build gravitational-wave detectors, including engineers, architects, geologists, chemists and physicists. Not only that, but industrial partners would require people with highly technical and specialist skills. It is worth noting that people who have trained in gravitational-wave research have gone on to a wide range of different careers, such as in finance and banking, as well as working for tech companies like Facebook and Google. Of course, many have moved into the space industry, while others have gone into the defence industry.

WHAT IS THE BEST ROUTE INTO A CAREER IN GRAVITATIONAL WAVES?

A physics or an astronomy degree would be a good place to start. However, some members of the community have a mathematics degree so there are clearly several routes into the field. That said, a good foundation in physics is strongly recommended.

PROF IK SIONG HENG

Principal Investigator for GrEAT
School of Physics & Astronomy
University of Glasgow, UK

FIELD OF RESEARCH

Physics and Astronomy

RESEARCH PROJECT

The Gravitational-wave Excellence through Alliance Training (GrEAT) Network is a UK-China project that aims to build on the expertise and technology of the two countries and further gravitational research.

https://great.physics.gla.ac.uk/

FUNDER

Science and Technologies Facilities Council

SOME OPPORTUNITIES IN GRAVITATIONAL-WAVE ASTRONOMY

- The LIGO Laboratory offers Research Experience for Undergraduates (REU) summer internships at Caltech and at the Hanford and Livingston Observatories:

  https://labcit.ligo.caltech.edu/LIGO_web/students/SURF/

- Louisiana State University and the University of Florida offer REU internships in physics and astronomy, including gravitational-wave detection, numerical relativity and general relativity.

- In Canada, the National Science and Engineering Research Council (NSERC) funds undergraduate student research awards (USRAs). Opportunities for work in gravitational-wave detection and LIGO are available.

ASK PROF IK SIONG HENG

YOU ARE THE PRINCIPAL INVESTIGATOR FOR GrEAT. WHAT INSPIRED YOU TO START THIS LARGE-SCALE COLLABORATION?

I began working with scientists in China in 2012. During that time, I noted that there was already significant interest in gravitational-wave research in the country, and this increased exponentially after the first detection in 2015. So, when the opportunity came to apply for funding to setup the GrEAT Network in 2017, I just had to do it. There are so many talented researchers in China and it made sense to couple their interest in gravitational waves with the extensive expertise and experience of UK researchers in this field.

WHAT IS IT THAT EXCITES YOU ABOUT THIS PROJECT?

I find it very exciting that the GrEAT Network brings together two communities of talented people to exchange ideas and form new connections, resulting in new projects and perhaps new discoveries!

GrEAT INVOLVES STEM OUTREACH IN SCHOOLS. WHAT ARE THE BENEFITS OF OUTREACH WORK?

Personally, I believe that outreach has two goals. The first is to communicate the outcomes of our research to the general public. After all, most of our research funding is done using public funds, so it is our duty to ensure that our results can be understood by our funders. The second goal is to inspire the next generation of scientists and give them an idea of how science and the process of making new discoveries work.

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

I was always interested in space and would look up fiction and non-fiction books relating to it. However, when I was very young, I actually wanted to be a fighter pilot. Then, in high school, I decided that I wanted to be a physicist instead. It wasn't until I was in university that I realised I wanted to do astronomy, in particular gravitational waves.

WHAT ARE YOUR TOP TIPS FOR STUDENTS WHO WISH TO HAVE A SUCCESSFUL CAREER IN GRAVITATIONAL WAVES?

There are many resources, especially on the internet, that communicate gravitational-wave science to the general public in a wide range of languages. They should not be difficult to find and they are a good place to start learning about gravitational waves. It could also be useful to discuss the topic with your teachers or ask them if they can put you in touch with someone who you can chat with about gravitational waves. Perhaps even contact your nearest gravitational-wave research group to ask for a tour or an internship! Above all, be creative, work hard and stay focused on your dreams.

CAN YOU GIVE US ONE FUN FACT ABOUT YOURSELF?

I enjoy playing with LEGO, especially with my children. Actually, I probably use my children as an excuse to buy more LEGO!

MEET THE RESEARCH TEAM

MARIELA MASSO REID
FROM CARACAS, VENEZUELA
POSTDOCTORATE AND PROJECT MANAGER OF THE GrEAT NETWORK
INSTITUTE OF GRAVITATIONAL RESEARCH, UNIVERSITY OF GLASGOW, UK

WHAT KEY SKILLS DO YOU BRING TO THE GRAVITATIONAL-WAVE FIELD AND THE GrEAT NETWORK?

As a member of the LIGO Scientific Collaboration, I studied the thermal conductivity of silicon and silicon-bonded materials at cryogenic [very low] temperatures; this is crucial because the next generation of detectors will use cryogenic temperatures. I am also the project manager for collaborations involving the UK, China and India.

WHAT EXCITES YOU ABOUT THE GrEAT NETWORK?

Increasing the current network of gravitational wave detectors will be of huge benefit. The GrEAT Network facilitates links between the UK and China, meaning we can exchange knowledge and tackle challenges together. It is incredibly exciting to see all these partnerships happening already, so I am looking forward to seeing this collaboration flourish!

WHY DO YOU DO WHAT YOU DO?

I fell in love with astronomy at around age 7, and discovered physics soon after, so it has always been my dream to be a scientist. I discovered gravitational waves when I first came to Glasgow to study my undergraduate degree and I made it my mission to get involved in whatever capacity I could. I enjoyed my PhD so much, and all the challenges that came with it. It is good to be able to see the larger picture and understand how my project fits within the Network and in developing the necessary technology for a new generation of detectors.

TELL US A FUN FACT ABOUT YOURSELF.

I found astronomy through my love of books and Greek mythology as a kid! I also love animals with all my heart.

Find this article and accompanying activity sheet at https://futurumcareers.com/great-potential-why-china-and-the-uk-are-working-together-in-gravitational-wave-research

XILONG FAN
FROM CHINA
ASSOCIATE PROFESSOR
WUHAN UNIVERSITY, CHINA

WHAT KEY SKILLS DO YOU BRING TO THE GRAVITATIONAL-WAVE FIELD AND THE GrEAT NETWORK?

Together, with Glasgow's collaborators, I built a Bayesian method for jointing analysis of gravitational-wave and electromagnetic-wave data when I was a Newton Fellow at Glasgow University. When I went back to China, I helped Professor Heng make connections with some researchers in Chinese universities, who are now part of the GrEAT Network.

WHAT EXCITES YOU ABOUT THE GREAT NETWORK?

I get to meet more experts from different UK Universities and have been able to extend my research as a result.

TELL US A FUN FACT ABOUT YOURSELF.

After two years of research in Glasgow, my understanding of science has improved a lot, but so too has my footballing ability!

LAURA NUTTALL
FROM THE UK
SENIOR LECTURER IN GRAVITATIONAL WAVES
INSTITUTE OF COSMOLOGY AND GRAVITATION, UNIVERSITY OF PORTSMOUTH, UK

CAN YOU TELL US A BIT ABOUT YOUR RESEARCH IN GRAVITATIONAL WAVES?

I've been conducting research in gravitational-wave astrophysics for the last decade as a member of the LIGO Scientific Collaboration. There are a few different areas of research that I am involved with. One aspect is in characterising the LIGO detectors. Detector characterisation helps scientists to investigate and fix sources of noise, ensures LIGO detector data are of sufficient quality for astrophysical analyses, and validates detections. I am the co-chair of the LIGO detector characterisation group. This work nicely complements another aspect of my research, which looks at ways to improve methods for detecting gravitational waves from colliding black holes and neutron stars.

WHY DO YOU DO WHAT YOU DO?

I love solving problems and I can't think of a better way to spend my life than trying to solve the mysteries of the universe. It's an absolute privilege to tell people that, for my job, I get to I think about ways to find and study colliding black holes and neutron stars.

TELL US A FUN FACT ABOUT YOURSELF.

I'm a little obsessed with netball – I play in a local league and umpire matches as much as I can.

NILS ANDERSSON
FROM SWEDEN
PROFESSOR OF APPLIED MATHEMATICS, HEAD OF THE GENERAL RELATIVITY GROUP
UNIVERSITY OF SOUTHAMPTON, UK

TELL US ABOUT THE KEY SKILLS YOU BRING TO GRAVITATIONAL-WAVE FIELD AND THE GrEAT NETWORK.

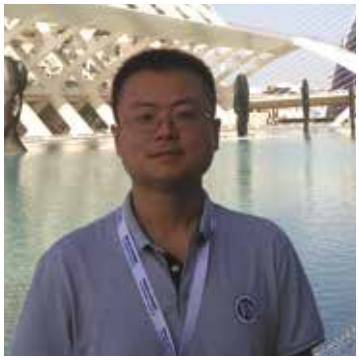
I am a theorist, so I bring an understanding of how gravitational waves work and their role in astrophysics. I also have a great interest in outreach and the public understanding of science. Within the GrEAT Network I help coordinate the data analysis and modelling work package, and recently hosted a group of Chinese students at a summer school in Southampton.

WHY DO YOU DO WHAT YOU DO?

I love what I do! My main interest is in the astrophysics of neutron stars. This involves many exciting aspects, especially as neutron star physics represent many extremes of physics (at the edge of our current understanding).

TELL US A FUN FACT ABOUT YOURSELF.

I write children's books.



YAN WANG
FROM CHINA
ASSOCIATE PROFESSOR
HUAZHONG UNIVERSITY OF SCIENCE AND TECHNOLOGY, CHINA

WHAT KEY SKILLS DO YOU BRING TO THE GRAVITATIONAL-WAVE FIELD AND THE GrEAT NETWORK?

I bring skills and experience in gravitational-wave data analysis and astrophysical source modelling for space-borne laser interferometers (aiming at detecting milli-hertz gravitational-wave signals) and Pulsar Timing Arrays (aiming at detecting nano-hertz gravitational-wave signals). Previously, I was a member of the North American Nanohertz Observatory for Gravitational Waves (NANOGrav), which is part of the international Pulsar Timing Array (IPTA) consortium. I was mainly working on the data analysis method for detecting and estimating continuous wave signals from individual supermassive black hole binaries. After joining the Center for Gravitational Experiments (CGE) in Huazhong University of Science and Technology, China, in late 2014 as a junior faculty member, I started to work for the proposed space-borne gravitational-wave detection project, TianQin.

WHY DO YOU DO WHAT YOU DO?

I do what I do in gravitational-wave research because of my enthusiasm and passion for figuring things out, and the potential for making exciting scientific discoveries. Besides, I appreciate the opportunities that I can display, using new insights from scientific developments, to the community at large through education and outreach.

TELL US A FUN FACT ABOUT YOURSELF.

I like swimming and practising Chinese calligraphy to relax after a long day at work. Recently, I started fishing with my wife around the city (There are hundreds of lakes and ponds in Wuhan). Usually, we don't catch anything after a few hours of waiting, but it doesn't really bother us; we enjoy it regardless.

JENNE DRIGGERS
FROM THE USA
SCIENTIST
DIVISION OF PHYSICS, MATHEMATICS AND ASTRONOMY, CALIFORNIA INSTITUTE OF TECHNOLOGY, USA

WHAT KEY SKILLS DO YOU BRING TO THE GRAVITATIONAL-WAVE FIELD AND THE GrEAT NETWORK?

My research focuses on improving the sensitivity of the LIGO gravitational wave detectors. The first part of having a sensitive detector is having it up and running, so our team at the LIGO Hanford Observatory will take all of the pieces of technology developed within the LIGO Scientific Collaboration and implement them to make them work together as one whole gravitational-wave detector. We then measure and tune different components of the interferometer to set them each at their optimal working point. I have done work on the angular controls system, which ensures that our mirrors are controlled in such a way that they stay aligned and pointed at one another with high precision.

Our gravitational-wave interferometers are incredibly sophisticated devices, and they need many different kinds of theoretical and experimental efforts in order for them to be successful. I'm very happy that the GrEAT Network is bringing more people into the field of gravitational-wave detection!

WHY DO YOU DO WHAT YOU DO?

I love working at the LIGO Observatory because it allows me to work with some of the most sensitive detectors in the world, and I get to explore aspects of the universe that are impossible to study in any other way.

TELL US A FUN FACT ABOUT YOURSELF.

When I'm not doing physics, I love to go camping and hiking with my two dogs.

LETTING THE WORLD KNOW ABOUT GRAVITATIONAL WAVES

The GrEAT Network is dedicated to outreach activities. This means keeping the public informed about all the amazing knowledge gained from gravitational-wave research through summer schools, workshops and other public outreach activities. These activities are especially important because it means people like you will be able to learn new things about the universe and, potentially, be inspired to work in gravitational-wave astronomy or another aspect of space science.

SUMMER SCHOOLS

This year, the GrEAT Network has organised summer schools to encourage interest and participation in the field of gravitational-wave research, particularly among university students and graduates. Keep an eye out for more summer schools if you are at university and looking for postgraduate opportunities.

Sun Yat-sen University
The TianQin Gravitational Wave summer school was organised by Dr Yi-ming Hu and held at the Zhuhai Campus of Sun Yat-Sen University (SYSU). Approximately 80 students were involved, of which 50 were from SYSU. The school organised lectures and social events, as well as interactions with experts in the field. Lecturers from 10 universities were involved, including five members of the GrEAT Network (Professor Ik Siong Heng, Professor Giles Hammond, Professor Martin Hendy and Professor Tim Sumner).

Southampton Master School
The programme consisted of a four-day summer school-level series of master-class lectures on relativistic fluid dynamics and applications. Aimed at postgraduates and postdocs, the lectures covered a range of topics, from formulation to input physics and numerical simulations.

The aim was to explain what enters into state-of-the-art numerical relativity simulations of neutron star mergers, and explore what has to be done in order to develop a new generation of more realistic simulations – areas where the Southampton group has particular expertise and interests. The event was designed to be informal and collaborative, with students having the opportunity to present their own research.

Various experts in the field were invited to take part and give the lectures, such as LIGO member, Greg Comer. Over 20 students attended the classes, including six students from China, six from India, and other students from the UK.

University of Birmingham
A master class has been organised, where students will be given lectures for about a week by experts in the gravitational wave field. The students partake in a series of challenges and projects. At the end of the week, they are paired together and take part in projects at various institutions involved in the GrEAT Network. The students work alongside expert researchers in the fields of experimental and data analysis – both of which are key elements for gravitational-wave detectors.

The GrEAT team meet in Beijing

Members of the Southampton masterclass

The GrEAT team meet in Glasgow

NEW ZEALAND: CREATING A NATION OF CURIOUS MINDS

FIVE YEARS AGO, THE NEW ZEALAND GOVERNMENT SET OUT A TEN-YEAR GOAL FOR BETTER ENGAGEMENT BETWEEN SCIENCE, TECHNOLOGY AND SOCIETY. **HELEN SILLARS**, MANAGER FOR SPECIALISED INVESTMENTS, EXPLAINS WHY THE MINISTRY OF BUSINESS, INNOVATION AND EMPLOYMENT INVESTS IN STEM

In New Zealand, science, technology, engineering and maths (STEM) skills are highly valued and sought after across the economy: 90 per cent of New Zealanders see science and technology as important areas to study, which increase job prospects and potential earnings. Indeed, STEM skills are applied in a wide range of industries and more broadly in life. Some growing industries that make extensive use of STEM skills include health (for example, med tech, pharmaceuticals), food tech (for example, innovative product development and manufacturing), and ICT (for example, agritech, software and services).

In 2017, the tech sector created 2,830 new jobs, which is a 3 per cent increase since 2016. These new jobs were evenly split across the sector, from ICT to high tech manufacturing. We are, however currently experiencing shortages of employees with STEM skills in the health, engineering and IT industries. Demand for these skills will continue to increase as the Government puts more investment into these areas in order to create a strong and prosperous economy with adaptable and engaged people.

A NATION OF CURIOUS MINDS

New Zealanders want to hear about new scientific and technological breakthroughs, especially when it stems from work done in our own backyard. This can't happen if we aren't making sure that our people are equipped with the skills. Five years ago, in 2014, the Government set out a ten-year goal for better engagement between science, technology and society in all sectors of New Zealand society, and developed *A Nation of Curious Minds*. The initiative covers three action areas that focus on enhancing the role of education, public engagement with science and technology, and encouraging science sector engagement with the public. Essentially, the aims are to:

- increase the number of science and technology-competent learners, who choose STEM-related career pathways or further study;
- improve the public's understanding and engagement with science and technology; and
- create a more skilled workforce, using science and technology to meet New Zealand's needs.

The initiative identified that a major hurdle for encouraging STEM learning in schools is teacher confidence. The Curious Minds Participatory Science Platform works in several ways to increase teacher confidence and enable teachers to support students' engagement with STEM subjects. The platform has also enabled the science sector to build their relationship with schools and communities by providing funding to facilitate scientists, researchers and communities working together. The funding gives communities and students resourcing to work with researchers to develop locally relevant research questions, "be the scientist" and carry out investigations themselves, with researchers alongside.

OFF TO A GOOD START

Five years after the launch of this strategy, we have a lot of evidence and survey results from projects that suggest that we're off to a good start. This includes teachers reporting greater confidence in delivering science. The Unlocking Curious Minds contestable fund has

© Chris Williams

> *Ninety per cent of New Zealanders see science and technology as important areas to study, which increase job prospects and potential earnings. New Zealanders also want to hear about new scientific and technological breakthroughs, especially when it stems from work done in our own backyard.*

funded at least one project in every part of the country. These are targeting a range of ages, types of schools, and cover STEM skills and different delivery ideas.

When we released A Nation of Curious Minds, new technologies and ways of working were increasingly becoming embedded into our everyday lives, and continue to do so. We believed, and still do, that it is important that no one in society is left behind.

INNOVATION IN STEM

Some of life's most difficult questions can be answered by people who have STEM skills. Climate change, health challenges and technology advancements are just the starting point of why science, technology, engineering and maths are important to understand. Essentially, building STEM skills, and engaging with STEM will equip people to make well-informed decisions about how to address difficult questions and challenges.

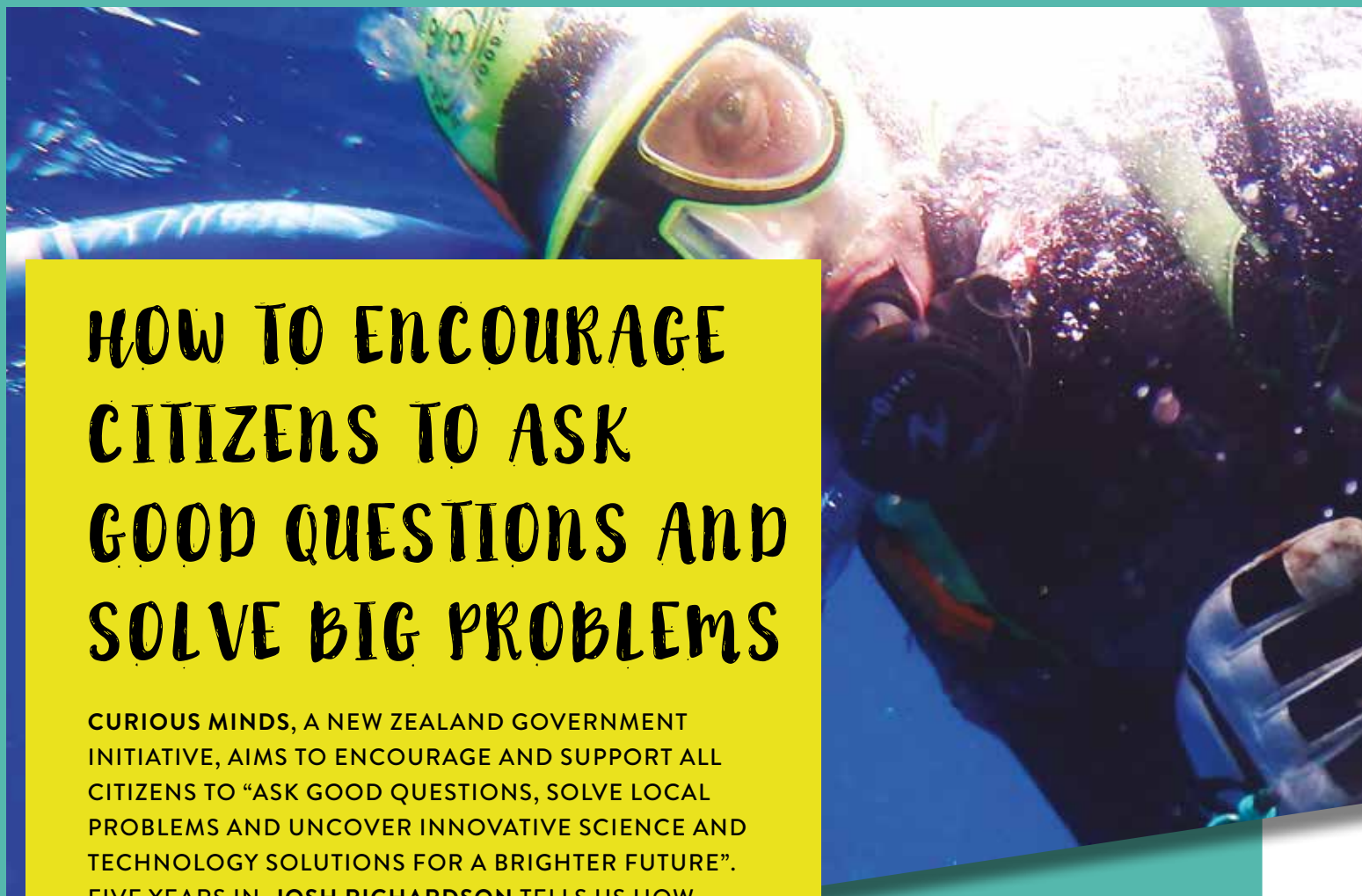
The Ministry of Business, Innovation and Employment's aim is to grow New Zealand for All. This means that we support the Government to make sure that New Zealand has prosperous and adaptable sectors, people and regions; our people are engaged in safe and fulfilling work; our consumers and businesses are informed and confident; and, finally, our value is sustainably derived and our business environment is dynamic, encouraging innovation and international connections.

EDUCATIONAL AND CAREER RESOURCES

For more information on the MBIE's Curious Minds initiative, read: How to encourage citizens to ask good questions and solve big problems.

The New Zealand Government has also introduced the following educational and career STEM resources:

- The Science Learning Hub is part of the Curious Minds suite of projects and is widely used across New Zealand schools: https://www.sciencelearn.org.nz/
- The Ministry of Education recently launched new resources on Progress and Achievement in science for New Zealand schools: http://scienceonline.tki.org.nz/Progress-and-Achievement-in-Science.



HOW TO ENCOURAGE CITIZENS TO ASK GOOD QUESTIONS AND SOLVE BIG PROBLEMS

CURIOUS MINDS, A NEW ZEALAND GOVERNMENT INITIATIVE, AIMS TO ENCOURAGE AND SUPPORT ALL CITIZENS TO "ASK GOOD QUESTIONS, SOLVE LOCAL PROBLEMS AND UNCOVER INNOVATIVE SCIENCE AND TECHNOLOGY SOLUTIONS FOR A BRIGHTER FUTURE". FIVE YEARS IN, **JOSH RICHARDSON** TELLS US HOW THIS INITIATIVE AND ITS WORLD-FIRST PARTICIPATORY SCIENCE PLATFORM IS FARING

WHEN AND WHY WAS CURIOUS MINDS SET UP?

Curious Minds came to life in 2014 through the development of the National Science Challenges, which were set up to address New Zealand's most pressing health and environmental issues, as well as advance our economy through innovation. The panel involved in setting up these challenges recommended a "Science in Society leadership challenge", which they felt was critical to the success of all the other challenges. Curious Minds was borne out of this challenge encompassing several different initiatives, the Participatory Science Platform (PSP) being one of them.

IS CURIOUS MINDS AIMED AT ANY GROUP IN PARTICULAR, FOR EXAMPLE, TEACHERS, CHILDREN, RESEARCHERS?

The goal of Curious Minds is to increase the science and technology capability within New Zealand society. While this sounds broad there are some key target groups that have been identified to provide the biggest impact. These are:

- Students, teachers and the compulsory learning sector
- Parents, whānau (extended families) and communities
- Science sector, including technology
- Business, especially science and technology-led businesses
- The public sector and government
- Communicators of science

> *"At Curious Minds, we are looking for a future where people are enabled and empowered through science and technology. Some of the biggest issues we are facing as a nation – and planet – could ultimately be addressed through science and technology, and we need to have a population that is comfortable with that process."*

CURIOUS MINDS AIMS TO ENCOURAGE AND SUPPORT ALL NEW ZEALANDERS TO "ASK GOOD QUESTIONS, SOLVE LOCAL PROBLEMS AND UNCOVER INNOVATIVE SCIENCE AND TECHNOLOGY SOLUTIONS FOR A BRIGHTER FUTURE". CAN YOU GIVE US SOME EXAMPLES OF "GOOD QUESTIONS"?

The exciting thing about Curious Minds is that it encourages people from all walks of life to ask all kinds of questions. Because of this we get a diverse range of topics investigated. For example:

Project Reef Life

- Ngāti Tawhirikura hapū (a Māori kinship group or tribe in Taranaki) worked with our local museum to investigate whether the Motunui Epa (200-year-old carved panels) were created with stone or wooden tools.

- Students from two New Plymouth High Schools worked with Massey University to ask questions around how interference is impacting the wireless connectivity of rural Taranaki.

- Woodleigh School students asked if they could create natural alternatives to repelling mosquitos in their outdoor classroom.

- Te Rūnanga o Ngāti Mutunga wanted to learn more about the distribution of frogs in North Taranaki and what this distribution indicated in terms of eco-system health.

WHAT TYPES OF "LOCAL PROBLEMS" ARE NEW ZEALAND'S CITIZENS SOLVING AND HOW?

Many of our projects focus on local environmental issues and end up contributing really important information. We frequently see projects sharing results with other groups, as well as governing bodies and decision makers. A couple of examples include:

- Project Hotspot, which has worked with schools to collect information on coastal species that were at risk or threatened. Through this work they identified plastic shotgun wads washing up on beaches. Working with the community and Taranaki Fish and Game, the results from this project led gun clubs to establish policies around the use of biodegradable wads, drastically reducing the amount of plastic put into the environment through this sport.

- Project Reef Life has been working since 2015 to document and monitor marine biodiversity within the South Taranaki Bight. Because there is little information currently available in this area, their findings have been used to inform the Taranaki Regional Council's Coastal Plan.

THE PSP BUILDS ON CITIZEN SCIENCE, ENCOURAGING PEOPLE FROM ALL WALKS OF LIFE TO ENGAGE IN LOCAL AND RELEVANT RESEARCH PROJECTS. DESCRIBED AS A "WORLD-FIRST INITIATIVE", WHAT MAKES IT SO UNIQUE?

The PSP is a process for collaboration and shared learning. It is a marriage between community action and science where all partners are equally involved in every step of the journey. Participants

ABOUT JOSH RICHARDSON

Josh is the Area Lead for the Participatory Science Platform (PSP) in the Taranaki region of New Zealand. He is passionate about engaging the public in STEM.

"From my own experience, science has opened so many doors and allowed me to explore the world around me. I think, in the past, we (scientists) have done a bad job of highlighting the relevance of science to people's everyday lives, and because of this many people might think that science, and STEM in general, is beyond their understanding. Engaging people in science and giving them the opportunity to explore a topic that is important to them is a great way of shifting attitudes and increasing confidence in STEM."

ABOUT THE PARTICIPATORY SCIENCE PLATFORM

Curious Minds' Participatory Science Platform (PSP) is a world-first initiative that aims to engage communities of all kinds in research projects that are locally relevant and have robust science/technology outputs with quality learning outcomes. The PSP funds projects aimed at enhancing teaching and learning, engaging communities with science and tech, connecting research with society, and promoting mentoring through an ambassadorship programme.

https://www.curiousminds.nz/

are involved through each aspect of the scientific process, from generating questions and hypotheses, to method development, implementation, analysis and communication of results.

A PSP project requires more than community exposure to science, or participation in a certain element of the process, it requires full integration and co-creation. Because of this we see projects that are consistent with our "locally relevant" ethos. These projects support two-way learning opportunities where scientists are getting more than data from a community but a suite of cultural, contextual and environmental learnings.

HOW CAN SCHOOLS GET INVOLVED?

While the PSP is not designed to be exclusively run through schools, many of our projects partner with schools and other education groups. Since 2015 we have had 43 schools involved in PSP projects in Taranaki alone. Some schools decide to run projects themselves, but most tend to join a project run by an outside organisation. What we are observing is that, for many teachers, this opportunity to work on a PSP project allows them to grow their confidence in science, and often leads to schools continuing to increase their science programmes even after their involvement ends.

WHAT HAVE BEEN THE MOST NOTABLE BENEFITS OF THE PSP?

From my perspective the most notable benefits are:

1. The PSP has created an avenue for collaboration between the science sector and the Taranaki community that goes beyond a crowd-sourcing approach.

2. Schools are being given greater opportunity to incorporate science learning into their programme through meaningful project work. This is also leading to increased teacher confidence in delivering science education.

3. Relationship building between different organisations, age demographics, and cultural groups. One key example of this is students getting to work alongside scientists, breaking down preconceived conceptions of what a scientist is or does. It also offers line of sight to a wider range of career opportunities, which is particularly beneficial to some of our rural students.

4. Filling gaps in information. Many of our projects contribute new information, particularly to the understudied aspects of our environment.

Stone vs. Metal - Motunui Epa

THE NEW ZEALAND GOVERNMENT HAS A TEN-YEAR GOAL FOR BETTER ENGAGEMENT BETWEEN SCIENCE, TECHNOLOGY AND SOCIETY, INITIATED IN 2014. FIVE YEARS IN, CAN YOU GIVE AN EXAMPLE OF HOW CURIOUS MINDS IS ACHIEVING THIS GOAL?

Because of this initiative the Taranaki community has had the opportunity to collaborate with over 70 different science and technology experts. Nearly 50% of all schools in the region have participated in research science and over 1,000 people have been actively engaged. Because we don't have a university in Taranaki, nor any research institutes, we would not have the level of science and technology engagement in the community we have presently without the PSP.

TO DATE, THE PSP IN TARANAKI HAS FUNDED 39 PROJECTS. THESE TWO PROJECTS ARE CURRENTLY ACTIVE AND ARE TACKLING IMPORTANT ISSUES WITHIN NEW ZEALAND'S COMMUNITIES:

- NGAMATAPOURI SCHOOL MONITORS THE WAITOTARA RIVER – this rural school of eight students is doing some amazing things. In this isolated area, flooding by the Waitotara River is a regular hazard that has had devastating impacts on the community in the past. Students are working with scientists and engineers to create their own flood warning devices that will send a signal to the school and local residents to warn them about rising water levels. The students are also doing regular water quality monitoring and mapping the way the river changes over time using a drone.

- TRASHFORMERS – This project is led by Upcycle Taranaki and a team of young people from a variety of schools around New Plymouth. The team is investigating the potential to use recycled plastics collected from beach cleans to make a variety of products, including building materials. The students have had to design methods for identifying the degraded plastic; they've engineered an extruder machine that melts down and reforms plastic; and they will be carrying out strength testing on the newly formed products.

Ngamatapouri School monitors the Waitotara River

Trashformers

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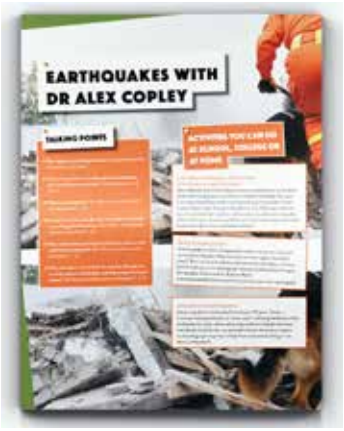

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