futurum

A SCIENCE, RESEARCH AND TECH MAG
FOR THE NEXT GENERATION

ISSUE 007
MARCH 2021

007 LICENCE TO SKILL

ALSO IN THIS ISSUE

BMW GROUP EDUCATION
BMW CARS HAVE FEATURED IN JAMES BOND FILMS BUT HOW DOES A CAR MANUFACTURER PUT STUDENTS ON THE ROAD TO SUCCESS *IMAGES PROVIDED BY BMW GROUP.*

THE SCIENCE OF JAMES BOND
ARE 'BOFFINS' BEHIND THE SUCCESS OF THE JAMES BOND SPY-FI FRANCHISE?

SCIENCE IN THE MOVIES
WHY IS STUNT SCIENTIST STEVE WOLF ON A MISSION TO INSPIRE YOUTH INTO STEM?

GANG CULTURE
WHAT CAN STREET YOUTH GROUPS TEACH US ABOUT EMPATHY, RESPECT AND SOLIDARITY?

BE PART OF A SCIENCE EDUCATION COMMUNITY

Want more articles like these from researchers, students and science-related organisations?

By signing up to Futurum Careers, you are subscribing to a community of scientists, educators, employers, students – people like you – who want to show the world just how fascinating and rewarding a career in the sciences can be.

WHAT'S IN IT FOR YOU?

As a member of Futurum Careers, you'll receive:

- The latest articles from academics, scientists and science-related organisations
- Teaching and classroom resources relating to specific topics in the sciences
- Careers resources, including 'How to' guides, information on apprenticeship schemes, and interviews with employers and young people studying degree courses
- All of the above sent to you once a month for free. We won't swamp your inbox

To sign up for free, visit: www.futurumcareers.com/sign-up

SCAN TO SIGN UP

futurum

A NOTE ABOUT YOUR PRIVACY

Your privacy is very important to us. We will not share, sell, reveal, publicise or market your details in any way, shape or form.

Our full privacy policy can be found on the Futurum Careers website: www.futurumcareers.com/privacy

007: LICENCE TO SKILL

In our database, we number our issues in the following way: 001, 002, 003, etc. When we reached our seventh issue and placed our first article into the 007 folder, James Bond immediately came to mind. At first, this seemed an arbitrary choice, but when we discussed this further, it increasingly made sense. Films play a significant role in shaping our perceptions of science and scientists.

James Bond tops all the blockbuster films, including Harry Potter and Jurassic Park. It seems generation after generation cannot get enough of spy-fy – the secret agent, Q, the gadgets and the villainous boffins, whose madness borders on genius. Author of *The Science of James Bond*, Mark Brake provides us with a fascinating insight into why the James Bond franchise enjoys such enduring success (p11).

Then there are the stunts. Stunt scientist Steve Wolf (p 8) has worked on film sets all over the world, using science to blow up cars and enable stunt performers to crash safely into shop fronts or trees. He now uses six carefully orchestrated stunts to teach schoolchildren across the US over 100 core STEM concepts, from thermodynamics to machine mechanics to health and safety.

Over the years, James Bond films have adapted to their time, paying homage to the latest technologies and innovations of the era (nuclear energy, space travel, bioweapons, cybersecurity) and becoming (or attempting to become) more inclusive. And, just as film lovers are fascinated by Q's latest technical inventions, we are in awe of the researchers who have shared their projects with us in this issue - they are at the forefront of innovation; they are dedicated to equality, diversity and inclusion, and they are on an important and vital mission: to inspire the next generation into STEM, STEAMM and research.

Our researchers are heroic agents of change, too!

KAREN LINDSAY
Director and Editor-in-Chief

ERICA MORGAN
Assistant Editor

BRETT LANGENBERG
Director

CHRIS DOWELL
Project Manager

T: +44 117 9099150

E: info@futurumcareers.com

W: www.futurumcareers.com

OUR WRITERS

Jacob Ashton, MA
Rebecca Ingle, PhD
Paul Redmond, MA
Alex Reis, PhD

JOIN US

@FUTURUMCareers
@Futurumcareers
Futurum Careers
@futurumcareers

OUR GRAPHIC DESIGNER

Claire Leach, BA (Hons)

PUBLISHED BY SCI-COMM CONSULTING
A limited company registered in England. Company No: 10791252

CHECK OUT OUR CAREER POWERPOINTS ONLINE!

Some of our articles also have translations into other languages. For example, you can access the Spanish version of Dr Verónica Segarra's article (p 70) here: **https://futurumcareers.com/understanding-cells-and-fostering-love-for-science**

CONTENTS

RESEARCH ARTICLES

14 THE SCIENCE OF THE VERY SMALL HAS ENORMOUS POTENTIAL Dr Wouter Deconinck

18 MECH-ING ENDOSCOPIES SAFER BY USING ROBOTS YOU CAN SWALLOW Dr Mark Rentschler

22 HOW CAN ROBOTS HELP US WALK? Dr Elliott Rouse

26 THE SKY'S THE LIMIT: NEW HORIZONS FOR AEROSPACE Professor Kristi Morgansen

30 HOW MICROBES IN ICELAND CAN TEACH US ABOUT POSSIBLE LIFE ON MARS Dr Solange Duhamel and Dr Christopher Hamilton

34 IN THE KNOW: BUILDING A CLIMATE LITERATE SOCIETY Dr Lesley-Ann L. Dupigny-Giroux

38 HOW DOES CLIMATE CHANGE AFFECT WATER QUALITY? Professor Li Li

42 UNDERSTANDING HOW AIR POLLUTION SPREADS Dr April Hiscox

46 DETECTING TOXIC SUBSTANCES FOR A GREENER AND HEALTHIER WORLD Dr Wenping Yin

50 HOW COMPUTATIONAL CHEMISTRY COULD USHER IN A SUSTAINABLE FUTURE Professor John Keith

54 MODERNISING MACHINE MEMORY Professor Xiaochen Guo

58 DISCOVERING HIDDEN PATTERNS IN DATA Dr Eric Chi

62 CONNECTING THE DOTS BETWEEN SCIENCE AND BUSINESS Dr Helen Boylan, Dr Alison DuBois and Mr Brian Petrus

66 EDITING GENES TO BENEFIT SICKLE CELL DISEASE PATIENTS Dr Natalia Rivera-Torres

70 UNDERSTANDING CELLS AND FOSTERING LOVE FOR SCIENCE Dr Verónica Segarra

74 HOW CAN STEM EDUCATION PROVIDE 'LIGHT-BULB' MOMENTS? Dr Liz Johnson

78 HOW TO CREATE 'GENIUSES' IN GEOSCIENCE Dr Sheldon Turner

82 START NOW TO REAP THE REWARDS LATER Dr Shad D. Nelson

86 BUILDING INCLUSIVITY INTO ASTROPHYSICS Dr Rodolfo Montez Jr. and Christine Crowley

90 HELPING LOW INCOME STUDENTS BECOME PROFESSIONAL SCIENTISTS
Professor JiaJia Dong, Professor Karen Castle and Professor Mary Beth Grey

94 MAKING TEACHING AS INCLUSIVE AS POSSIBLE
Dr Christina H. Paguyo and Dr Valentina Iturbe-LaGrave

98 DID YOU KNOW THAT GANGS ARE NOT ALL ABOUT CRIME AND VIOLENCE?
Dr Carles Feixa Pàmpols and Dr José Sánchez García

INTERVIEWS

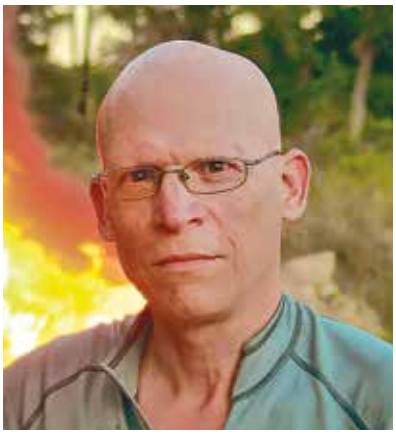
4 **MANDY BUCHANAN**, TALENT DEVELOPMENT MANAGER, BMW GROUP

8 **STEVE WOLF**, FOUNDER, SCIENCE IN THE MOVIES

11 **MARK BRAKE**, AUTHOR, *THE SCIENCE OF JAMES BOND*

102 **CÉSAR ANDRADE ARTEAGA**, LATIN KINGS GANG MEMBER AND RESEARCHER, TRANSGANG

P4



P8

p11

"WHO ISN'T GOING TO THINK WHATEVER JAMES BOND IS DRIVING IS THE COOLEST CAR ON THE PLANET?!"

BMW CARS HAVE FEATURED IN MANY BLOCKBUSTER FILMS, INCLUDING JAMES BOND AND MISSION IMPOSSIBLE, BUT IS THERE MORE TO WORKING WITH A CARMAKER THAN ITS KUDOS AND WORLD-FAMOUS BRAND? **MANDY BUCHANAN**, TALENT DEVELOPMENT MANAGER, INVITES US TO EXPLORE **BMW GROUP'S** INSPIRATIONAL – AND FREE – CAREERS AND EDUCATION RESOURCES

BMW CARS HAVE APPEARED IN MANY JAMES BOND FILMS OVER THE YEARS, INCLUDING *GOLDENEYE* AND *TOMORROW NEVER DIES*. WHAT ARE THE BENEFITS OF BEING INCLUDED IN HIGH PROFILE FILMS LIKE JAMES BOND?

Similar to television advertising, product placement in high profile films is a fantastic way to promote a car and brand to a broad audience. *Goldeneye* is a perfect example. Its premier in Germany was on December 28, 1995, and this night was also used to launch the BMW Z3, which featured in the film. Showing the car for the very first time at the premier was a really clever way of drumming up excitement and gaining lots of media attention. But perhaps one of the top benefits in including your product in a high profile film is endorsement. James Bond is a globally renowned secret agent, known for his high-end gadgets and top-of-the-range sports cars. Who isn't going to think whatever he's driving is the coolest car on the planet?!

CAN YOU DESCRIBE SOME OF THE DESIGN/ TECHNOLOGICAL FEATURES THAT MAKE BMW CARS UNIQUE?

BMWs are unmistakable at first glance, which is down to a few defining features. For example, the BMW radiator grille at the front of the car is called 'the kidney' due to its shape. Additionally, BMWs have a distinctive crease line, which starts from the front and sweeps down the side towards the rear of the car. This gives BMWs a unique, tapered shape and sense of movement, even when the car is stationary.

Technology is at the heart of every BMW, from the engine, efficiency and the way the car drives, through to the touch screen inside the car and unique apps. For example, the newly launched My BMW app lets drivers access their car from their smartphone so that they can check how much fuel or electric range is in the car, lock it and even start it up and make sure it's warm before they get in to drive!

ARE THERE ANY EXCITING TECHNOLOGICAL ADVANCES THAT ARE DUE TO BE ROLLED OUT IN THE NEAR FUTURE FOR BMW CARS?

Yes, perhaps the most exciting yet! Later in 2021, BMW is launching its new technology flagship, the BMW iX – an all-electric SUV with the company's very latest innovations in the fields of electrification, automated driving and connectivity. Stay tuned!

CAN YOU GIVE A SENSE OF THE BREADTH OF STEM SKILLS NEEDED TO DESIGN A BMW CAR?

Science, technology, engineering and maths skills are integral throughout the whole BMW design process. After initial sketching, a BMW is designed and developed virtually using computer aided design (CAD). The design has to be very closely linked with engineering to ensure the technology, hardware and components can be safely positioned within the vehicle. Clay modelling is used by designers to create a physical product, allowing a visual reference and precision shaping to the millimetre.

The design also considers biological science: what makes a BMW visually pleasing and evokes emotion? Of course, not only must the car look good, it has to keep passengers safe, and physics and maths play a crucial part in this. For example, a designer must consider the qualities and composites of a material: how does it behave if it catches fire or is impacted in an accident?

WHAT ABOUT THE ARTS? DOES BMW REQUIRE ARTS GRADUATES?

Absolutely! Diversity in business is crucial for ongoing development and success, and we need talent that can respond to an ever-changing world of work. Creative thinking and expression through arts as well as business partnerships are essential for building healthy businesses and vibrant communities.

BMW OFFERS APPRENTICESHIPS, INTERNSHIPS AND THE GRADUATE PROGRAMME. WHAT QUALITIES DOES THE

BMW vehicles featured in the James Bond films: GoldenEye, Tomorrow Never Dies and The World is Not Enough. Credit: Mutschler, Hardy, BMW Group Archive

CARMAKER LOOK FOR IN ITS APPRENTICES, INTERNS AND GRADUATES?

We look for positive and enthusiastic individuals, who are passionate about the BMW brand and have a desire to learn and develop within the company. We want creative and organised people, with excellent interpersonal skills and the ability to work successfully both individually and within a team.

HOW MANY APPRENTICES, INTERNS AND GRADUATES ARE RECRUITED EACH YEAR?

Approximately 260 Future Talent positions are recruited from across the UK each year. This includes apprentices, interns and graduates. We typically receive 18,000 applicants for those positions.

WHAT ARE YOUR TOP TIPS FOR STUDENTS CONSIDERING A CAREER WITH A CARMAKER LIKE BMW?

I think one of my top tips would be to really do your research. There will be many different areas available in the business to work in, from the more practical roles such as engineering, manufacturing and design, to the more corporate roles such as public relations, marketing or finance. Think about what you're passionate about, love doing or are perhaps already studying, and find out what job opportunities those skills can lead to. It's also important to understand the criteria needed to fulfil a role within the business, and have a list of what you need to do or work towards to apply.

Doing your research is also incredibly important when it comes to applications and interviews. Do your family or friends have any contacts in the industry who might be able to offer you valuable insights? What can you learn from articles or books? What's the company's latest news? Building up a good foundation of up-to-date knowledge will really help you stand out in any interviews as your passion and enthusiasm will shine through!

MEET MANDY BUCHANAN

I wanted to be an actress or a teacher when I was younger. The closest I got to both were amateur dramatics and becoming a qualified trainer for leadership and personal effectiveness topics. I spent 26 years building my HR career within a STEM organisation before joining the fantastic HR team at BMW Group, just before my 50th birthday.

As Talent Development Manager, I work with some great people to help managers develop, assess and promote their employees, and ensure we have the most diverse and inclusive working conditions/arrangements to make us an attractive employer.

What is my top tip? Being an adult is hard work, full of important decisions including what to make for dinner every single day, so don't wish your youth away – enjoy it!

The BMW 750iL (E38) featured in James Bond: Tomorrow Never Dies in 1997. The vehicle was equipped with rocket launchers in the sunroof. Credit: Mutschler, Hardy, BMW Group Archive

WHAT CAN BMW OFFER YOU?

EDUCATION

BMW GROUP EDUCATION WAS SET UP TWENTY YEARS AGO TO PROVIDE TEACHERS AND STUDENTS WITH FREE, CURRICULUM-LINKED EDUCATIONAL RESOURCES

"The BMW Group is extremely conscious of its role in society and responsibility to support young people with learning about all aspects of mobility. As a car manufacturer, we have a wealth of industry knowledge, from the more practical – road safety and driving – through to wider topics such as global environmental impact, sustainability and energy use. We want to educate and inspire the next generation who will play a role in shaping the future of mobility." - MANDY BUCHANAN

Intelligent Living (i-Living) is BMW Group Education's interactive learning resource aimed at students aged 11-16 years.

https://bmweducation.co.uk/i-living/

There are three online learning modules (see below), all of which include Teacher's Notes and Student Sheets.

GLOBAL DEVELOPMENT	URBAN MOBILITY	SUSTAINABLE WORLD
What is sustainability? And how does it address the tension between global issues such as climate change and meeting human needs as the world's population grows? **https://bmweducation.co.uk/i-living-interactive/global_development.html**	With sustainability in mind, how would you change the way you and/or others move around your city, town or village? **https://bmweducation.co.uk/i-living-interactive/urban_mobility.html**	What is the difference between renewable and non-renewable energy sources? What do designers need to consider to design sustainable products? **https://bmweducation.co.uk/i-living-interactive/sustainable_world.html**

CAREERS

BMW GROUP GIVES STUDENTS THE CHANCE TO EXPLORE DIFFERENT CAREER OPTIONS AS AN INTERN OR APPRENTICE

"The global pandemic has meant our recruitment drive has gone virtual, including our marketing materials, open evenings, assessment centres and interviews. During the UK's National Apprentice Week 2021, we ran three virtual events, where applicants and parents were invited to see what we can offer, including application hints and tips and testimonials from existing apprentices." - MANDY BUCHANAN

BMW Group's careers webpages offer all the information you need to "turn your visions into reality, help shape the future of mobility and start the career of your dreams with the BMW Group".

https://bmweducation.co.uk/careers/

BMW 750iL (E38) featured in James Bond:
Tomorrow Never Dies in 1997. ***Top:*** *a console behind the driver's seat enabled James Bond to control the car without being seen.* ***Bottom:*** *A gear saw was built into the BMW emblem on the car bonnet. Credit Mutschler, Hardy, BMW Group Archive*

MEET TIA

MAINTENANCE TECHNICIAN APPRENTICE

"I've always been eager to understand how things worked. At school I was interested in the computer science and engineering subjects – I asked loads of questions! Learning new skills, being hands on and making components out of different materials is so interesting to me. Cars are definitely my biggest passion, so working towards my Level 3 Maintenance Engineer Apprenticeship at BMW Group is a dream come true.

My main role here is to ensure the lines keep running and that all the machinery that makes the car parts is maintained to the highest standard. Day to day, I also undertake preventative maintenance activities so that machines are regularly checked for safety and overall function.

Spending my weekends working alongside my dad, tinkering with his cars, putting in new parts and upgrading the systems has definitely led me to where I am today. And I think being a very sociable person also means that BMW Group is a good fit for me, because you get to meet lots of people within the plant and across the global business – the networking is incredible.

The best part of my apprenticeship is waking up for work and knowing that I'll experience something new. Every day is different, and that is exciting as I'm constantly gaining skills and experiences that will help me in my future career."

Find out more about apprenticeships here:
https://www.bmwgroup.jobs/gb/en/opportunities/apprentice.html

MEET FAITH

FORMER ASSEMBLY PLANNING INTERN

"As part of my degree in mechanical engineering I have to do an industrial placement each year. I was lucky to be accepted onto two placements with BMW Group, the first was with the Aftersales Technical Services team at Rolls-Royce, and now with MINI as an Assembly Planner for Structure, Controls and Facility. I had an offer from another business, but I'd had such great feedback and development through my first placement I was keen to return to the Group.

I was given autonomy and responsibility from day one. I worked with the technical specialists in a range of activities including looking at vehicle component design and supporting the continuous improvement of our products and services. I evaluated, produced technical documentation and improved service diagnostic tooling both at the software and hardware level. I've learned so much and my professional skills and technical capabilities really improved. There is a real commitment to future mobility here. If you want to be a part of the solution for tomorrow, it's a great place to be."

https://www.bmwgroup.jobs/gb/en/opportunities/student/popup-faith.html

SCIENCE IN THE MOVIES

STUNT SCIENTIST **STEVE WOLF** SPENT YEARS BLOWING UP CARS AND BUILDINGS FOR ALL THE MAJOR FILM STUDIOS, SO WHY DID HE TURN HIS ATTENTION TO EDUCATING YOUTH ABOUT STEM? HE COULD NOT BELIEVE THAT IN THE USA, THE COUNTRY THAT PUT A MAN ON THE MOON, CHILDREN WERE FALLING BEHIND SO DISMALLY IN SCIENCE AND MATHS

"How do we, as teachers, step up our game, entertainment-wise, so that we can compete for our children's attention on a level playing field?" asks Steve Wolf, an engineer, inventor, TV producer, science presenter, author and stunt scientist. It's a good question.

Modern technologies have catapulted a generation into a cyber world that didn't exist 10 years ago. Technologies like X-Box, PlayStation, Oculus, mobile phones and the internet are a gateway to great excitement but they can also steal attention away from school and learning. How can teachers compete?

If anyone can answer this question, it's Steve. And if Joe Biden's administration invited him to work on this problem on a national scale, he would. "We are unfairly leaving the next generation with a host of serious problems they didn't create," he says. "They're going to have to figure out issues of climate change; they're going to have to figure out how transportation will work without screwing up the planet; they're going to have to figure out challenges in medicine, as we're seeing with this pandemic. I feel a strong drive to enable kids to tackle the challenges they'll face. It's not fair to leave them problems without giving them the ability to solve them. But you can't just offer traditional education. You have to make it exciting and appealing."

INSPIRING STUDENTS WITH STUNT SCIENCE

Steve is the founder of Science in the Movies, and its aim is to get students excited about science. His team puts on live assemblies, performing movie stunts and special effects to schoolchildren all over the world. Incredibly, it takes just six carefully orchestrated stunts to teach over 100 core STEM concepts, ranging from thermodynamics to machine mechanics to health and safety (including drugs and alcohol). To date, Science in the Movies has performed in over 5,000 schools to over 2,000,000 students.

Can a one-hour assembly really inspire a generation of scientists? It's impossible to tell, but people of all ages come up to Steve to tell him how much they loved his show, nearly 30 years after his first stunt assembly. Teachers who have attended Steve's professional development courses are asking for his help to make their lessons more engaging. Pam Patterson, now retired from Berkley National Laboratory in the US, wrote: "If you think Steve Wolf has a special effect on movies, you won't believe the effect he's having on students' science scores. His influence on science education is being felt across the country."

Indeed, a study conducted in the state of Texas found that students who participated in Steve's assemblies scored up to 33% higher in their science tests than those who did not. It could be that the schools that hire Steve's Science in the Movies team are already more engaged with science, but in any case, it appears to be working.

"I don't remember much about my high school classes, but I remember all the assemblies," says Steve. "If someone came to talk to us, and they

STEVE WOLF

Stunt Scientist, Experience Engineer, Inventor, TV Producer, Science Presenter and Author

https://www.stevewolf.info/bio
https://www.scienceinthemovies.com

Source: Steve Wolf

STEVE'S TOP TIP

"If there's anything you want to learn, anything you want to be, find someone you respect who is doing it well, and put yourself next to them. Maybe you won't get paid at first, but you'll be creating an opportunity for yourself that no amount of schooling or money can rival. People hire people they know, like and trust. So, get known, be likeable, be trustworthy and doors will open for you."

were passionate and interesting, their message stuck with me for 40 years. Good assemblies stick with you and change you."

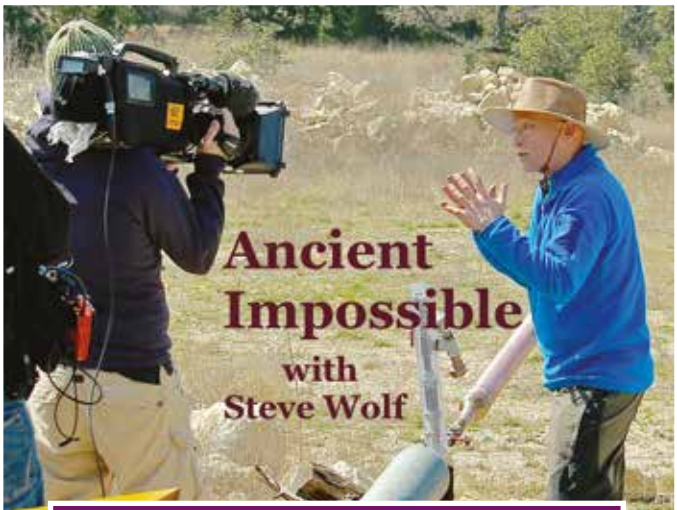
FROM STUNTS TO SCHOOL AND BACK AGAIN

Steve has been into stunts since he was six years old, learning mountain climbing and all the rescue skills associated with it in Geneva, Switzerland, where he grew up: "My first business was selling climbing lessons to my neighbours, showing them how to climb to the top of the big tree in my backyard."

After a exploring a career in emergency medicine as a paramedic, Steve decided to focus on academia, majoring in writing and literature, and minoring in Shakespeare and physics, at Columbia University in New York: "I liked reading and I liked writing, and if I could get through college with these two things, it wouldn't feel like work," he says. Steve worked on his studies at Columbia in the morning and drove an ambulance in the afternoon.

TENACITY

According to the *Oxford English Dictionary*, tenacity is, "the quality or fact of being very determined". It is a word that can certainly be applied to Steve. Deciding that there was no money in working for someone else, he bought an ambulance, started up a private company and chose to work on film sets as a stunt medic. Steve believed that most stunt accidents could



Steve hosts Ancient Impossible for the History Channel. Here, he is recreating a steam cannon, the first of which was invented by Archimedes. Source: Steve Wolf

be prevented if stunt performers applied science to their stunts, but "I got pushback from performers who preferred to 'cowboy' it," he says. After one stunt performer got hurt, and cost the production company time and money, Steve convinced the director that he could set up the same stunts and, by applying physics and physiology, ensure that no one would get hurt. The director hired him to stunt coordinate the rest of that film and several others.

"After a while, I realised that the stunt stuff was really just a big physics experiment with a human payload, with much of the engineering being done by the special effects department," Steve continues. "I realised I'd rather be on the special effects side, creating all the engineering. I started back at the beginning as a special effects intern."

If there is just one thing you take away from this article, it would be this: Steve scoured the credits of blockbuster films to see who worked on the special effects. One name kept cropping up: Gary Zeller. "I looked him up, called him, and told him that I wanted to work with him. I was not asking for a job, or to be paid. I just wanted the chance to prove my value, carry his tools, get him coffee, add value however I could." says Steve. It worked. "After a week, Gary hired me, then we formed a production company together, doing stunt and special effects commercials."

Then, after getting a big break leading the special effects team for the 1993 Tom Cruise thriller, *The Firm*, Steve was blowing up cars and buildings for all the major studies (Warner Brothers, Paramount, Disney) and working on stunts with stars like Brad Pitt and Samuel L Jackson.

WHAT'S LIFE ALL ABOUT?

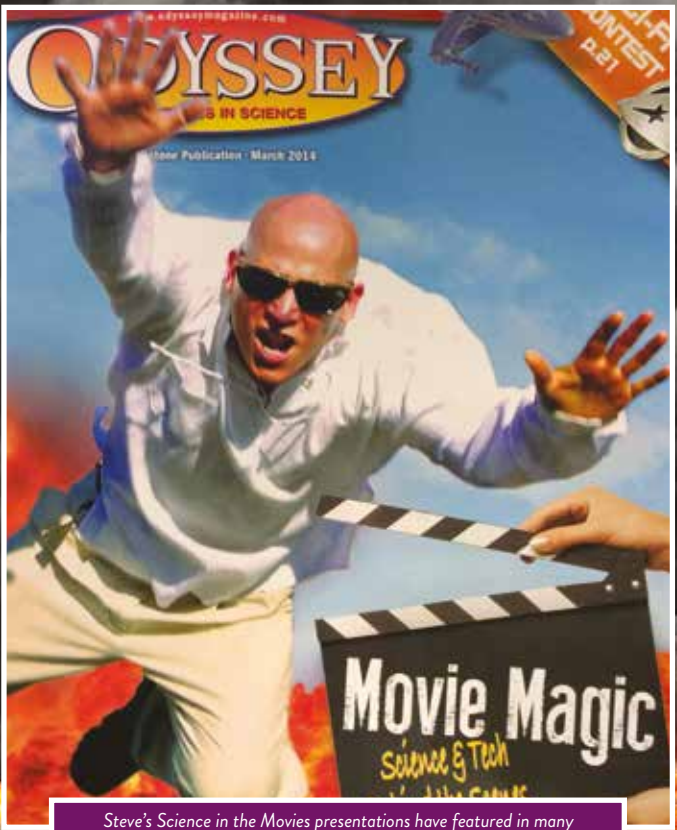
You would have thought that working on stunts and special effects with world famous actors would be exciting enough to last a lifetime. Not so for Steve.

"Working out the engineering, physics and chemistry involved in blowing up cars and buildings is exciting, but when you work on a movie set, there's a lot of time spent sitting around doing nothing," Steve explains. "I was sitting in my truck on a cold January day, when I saw a news story on TV that said that the United States had ranked 19th out of 20 for science scores. That threw me. When I was five, I watched Neil Armstrong walk on the Moon. How can you tell me we don't understand science? Kids haven't devolved evolutionarily since I watched that. If kids are failing in schools, it's because schools are failing the kids."

Steve considered becoming a teacher and studied for a master's in education, but it dawned on him that most teachers go into teaching thinking they will change the system until "the system eats them up". This was when Steve came up with the idea for Science in the Movies.

SCIENCE IN THE MOVIES

Since setting up Science in the Movies, Steve has been invited to present at the World Science Festival, the US Science and Engineering Festival, Dubai Science Festival, the Serbian Science Festival, among others. He has been awarded the Time Warner Science Presenter of the Year Award and has hosted and appeared on dozens of TV shows for networks, including Discovery Science. Steve is passionate about what he does, inspiring children all over the world to study STEM subjects and take up STEM careers, but that is not all. Steve hopes that by participating in Science in the Movies, children will look past the violence and gore so often portrayed in films to marvel at the science involved in making these films.



Steve's Science in the Movies presentations have featured in many publications, including Odyssey. Source: Steve Wolf

Don't try this at home! Steve demonstrates the chemistry involved in insulating his hand from fire. Source: Steve Wolf

"Every time you watch a movie, instead of seeing a house on fire as an act of arson, as it might be according to the script, think about it from a scientist's point of view," says Steve. "If you were the special effects coordinator, how would you create that effect? How would stop the fire when the director asks you to? Or, if the director wants bigger flames, how would you make that happen? What about producing black, grey or white smoke? How would you do that, from a scientific point of view?"

Of course, the global pandemic has meant that live events have been put on hold, including Science in Movies assemblies and field trips, but this does not mean that life has to come to a standstill. As Steve says, "This pandemic would barely have affected Hemingway or Shakespeare, until he wanted to put on a live performance at the Globe. For an inventor or a writer, this long-term solitude can be very useful." With this in mind, now is a very good time to try out Steve's activity sheet on the Futurum Careers website – and keep an eye out for his stunt science videos online!

THE SCIENCE OF JAMES BOND

MARK BRAKE, AUTHOR OF *THE SCIENCE OF JAMES BOND*, EXPLAINS WHY BOFFINS, MANIACS AND JETPACKS MAKE THE JAMES BOND SPY-FI FILMS THE HIGHEST-GROSSING FRANCHISE OF ALL TIME – OVER AND ABOVE HARRY POTTER AND JURASSIC PARK

IN YOUR BOOK *THE SCIENCE OF JAMES BOND*, YOU WRITE THAT JAMES BOND IS THE HIGHEST-GROSSING MOVIE FRANCHISE OF ALL TIME. WHY DO YOU THINK JAMES BOND IS SO SUCCESSFUL?

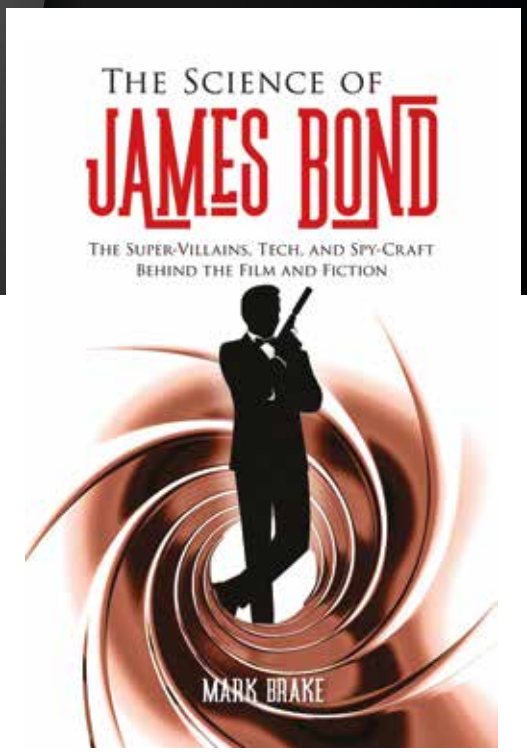
James Bond is the only international secret agent with a shelf life of almost 60 years. The genre of spy fiction grew a lot after WWII, during the so-called Cold War, when the world was split between the power Blocs of East and West. Like us, Bond lives in a changing world. He's a lone-wolf trying to save a chaotic world from itself. But the secret to Bond's success is that it's spy fiction with a twist. James Bond movies fuse spy fiction with science fiction, reflecting sci-fi's obsessions with super-villains, the future and world domination or destruction, along with plenty of entertaining gadgets, inventions and spy devices.

WHAT WOULD YOU SAY IS THE RATIO OF SCIENCE FICTION TO SCIENTIFIC FACT IN THE JAMES BOND FILMS?

The fiction and fact are fused together in each film. You can see the way the themes change from movie to movie, following Bond's progress whilst also looking at the bigger picture of science and tech in each plot. There's an exploration of space in *Dr No*, *You Only Live Twice*, *Moonraker* and *GoldenEye*. The films *For Your Eyes Only* and *Octopussy* focus on a world that is suffering from nuclear paranoia. And the movies *Skyfall* and *Spectre* look to a worrying future world where almost everyone is being spied upon using the intrusive technology of spy-craft.

CHAPTER ONE OF YOUR BOOK STARTS WITH A QUOTE FROM THE VILLAIN DR NO: "ALL THE GREATEST MEN ARE MANIACS. THEY ARE POSSESSED BY A MANIA WHICH DRIVES THEM FORWARD TOWARD THEIR GOAL. THE GREAT SCIENTISTS, THE ARTISTS, THE PHILOSOPHERS, THE RELIGIOUS LEADERS—ALL MANIACS." DO YOU THINK THERE IS AN ELEMENT OF TRUTH IN THIS?

American academic Camille Paglia says there are no female Mozarts. Genius, she argues, takes obsession, which produces good and bad talents, and skills. She thinks there are no female Mozarts because there are no female Jack the Rippers. I'm not so sure I believe in the idea of the lone-genius, working away in an isolated lab. There's still a kind of 'great men' myth about science: the false idea that progress in science is due solely to the genius of great men, irrespective of factors such as culture, society and economy. We're expected to believe that these masterminds just dream up stuff out of thin air. Many histories of science are rooted in the 'great men' myth. They are little more than a series of naïve narratives of great discoverers, each with their own momentous and revelatory insight into the secrets of nature. In truth, progress is the fruit of many ordinary thinkers and workers. Great men, and



EXTRACT FROM *THE SCIENCE OF JAMES BOND*

The Bond villain Blofeld's "Omega Virus threatens to wipe out entire species across the globe. Since the 1950s it has been possible to create deadly biological aerosols through the use of what's known as bursting bomblet technology. By the turn of the decade in which Blofeld finds himself, a B-47 bomber dispenser could infect over half of the population of a sixteen-square-mile area with infectious disease.

"So, rather than dealing in melodrama, Blofeld is dealing in real possibilities. In the *On Her Majesty's Secret Service* movie, Blofeld speculates to Bond that the Virus could be engineered to target humans. Science fiction in 1969 perhaps, but certainly not now. The production of such a virus to target humans rather than other animals is a rather straightforward affair today, one which would be within the biotech potential of many labs around the world."

women, have been a crucial factor. But their contribution should be seen in context, and not in isolation from their contemporary setting. An inability to see this often leads to the use of redundant words like 'brainwave' or 'genius' to explain away those eureka moments of discovery.

YOU EXPLAIN THAT "THE WORD 'BOFFIN' IS AN INFORMAL NAME, MAINLY BRITISH, WHICH IS GIVEN TO SCIENTISTS WHO KNOW MUCH ABOUT SCIENCE BUT LITTLE ABOUT ORDINARY LIFE; THOSE THINGS THAT MAKE US MORE HUMAN." DR NO IS A "GERMAN-CHINESE MALEVOLENT BOFFIN"; Q IS AN "ANTIQUATED OLD BOFFIN" WHO APPEARS IN MANY OF THE BOND FILMS; WHILE THE LATEST Q, APPEARING IN *SKYFALL*, IS "A BOFFIN OF THE MILLENNIAL KIND: ALL ANORAK, HEAVY RIMMED SPECS, AND COMPUTER ALGORITHMS". WHY ARE SCIENTISTS OFTEN PORTRAYED AS BOFFINS? DO YOU THINK THIS IS DAMAGING STEREOTYPE?

You have to think carefully about the way in which film and fiction portray the scientist. Science has produced, among many wonderful things, the bomb, the cyborg and computer systems capable of killing millions. Many scientists – perhaps most of them – believe that these accusations have been laid unjustly at their doorstep. These monster inventions, they would say, are the sins of technology: sins of applied, not pure science. But movies are unhappy with this muddled division of labour. So, movie-makers conjure up doctors such as Faustus and Frankenstein, and Jekyll and Strangelove, as a warning that mad doctors of science DO exist and that such images still sit in the public's imagination. Scientists are humans, capable of good and bad.

IN THE 1963 JAMES BOND FILM *FROM RUSSIA WITH LOVE*, THE SPECIAL EFFECTS CREW USED A MINI RADIO-CONTROLLED HELICOPTER INSTEAD OF A REAL ONE TO CREATE A TRUCK-VERSUS-HELICOPTER SHOOTOUT. DO YOU THINK ADVANCES IN SPECIAL EFFECTS TECHNOLOGY HAVE MADE THE JAMES BOND FILMS BETTER OVER THE YEARS?

Not necessarily. The relationship between special effects technology and movie plot is not that formulaic or mechanical. For example, almost 20 years ago, they put a lot of money into the CGI of *Die Another Day*. But with the video game James Bond bleeding out into cinema, the CGI-heavy *Die Another Day* had past the tipping point from espionage into comic book spectacle and excess. Bond became too unbelievable. And it took the grittier Daniel Craig, who really does look like he could kill you if he wanted to, to make Bond more believable again.

YOU ARE A SPECIALIST IN SCIENCE COMMUNICATION. WHY IS SCIENCE COMMUNICATION IMPORTANT?

The psychoanalyst Erik Erikson once said, "[humans] need to teach, not only for the sake of those who need to be taught, and not only for the fulfilment of [their] identity, but because facts are kept alive by being told, logic by being demonstrated, truth by being professed." Erikson called humans the 'Teaching Species', writing that a need to teach and help others grow is at the very centre of a human adult's identity. Our investment in those around us, in the form of science mentoring, is essential if we are to develop a healthy and supportive community, in a communal or global context.

WHAT DID YOU WANT TO BE WHEN YOU WERE YOUNGER?

My idea of what I wanted to be changed over time. Punk was big when I was young, so I set up a punk band and thought about a future in music. Times change, and your aspirations change too. I eventually got into science communication because I was passionate about the fascinating relationship between science and sci-fi, and I wanted to talk to people about this relationship.

WOULD YOU RECOMMEND A CAREER IN SCIENCE COMMUNICATION?

It's not for me to recommend what someone else might do. But I would say that the field of science communication is broad. It embraces the perspectives of many practitioners: scientists, historians, sociologists, journalists, communication theorists, politicians, philosophers and performers. It's all about the public's engagement with science. Its main aim is to somehow improve this engagement, so it's very important right now. Today, around the world, dodgy politicians appeal to people's worst instincts. Anti-science conspiracy theories, once confined to the fringe, are now mainstream. The age of reasoned argument is on the run. Expert knowledge and scientific consensus are dismissed. Democracy, which relies on shared truths, is in retreat, while autocracy, which depends on shared lies, is on the march. Science communication has never been more important.

FINALLY, WHAT IS YOUR FAVOURITE BOND GADGET AND WHY?

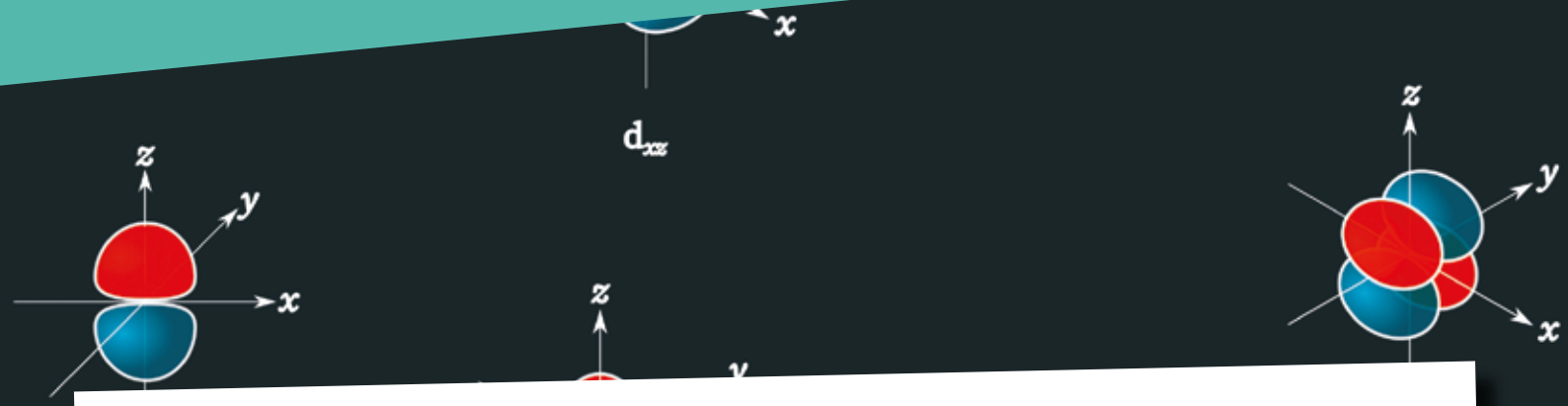
For me, it has to be the jetpack. *Thunderball* opens with Bond escaping using a jetpack, which once more firmly places Bond in spy-fi. The jetpack is a flying device, worn on a person's back, which uses jets of liquid or gas to propel the jetpack pilot through the air. The idea had been pretty common in sci-fi for most of the twentieth century but became particularly widespread in the 1960s. It wasn't until September of 2020 that a jet suit for paramedics was tested by the Great North Air Ambulance Service in the Lake District. The suit might mean that in the future mountain-rescue patients would be reached in minutes.

Mark Brake has an illustrious career in science communication, having worked with, among others, NASA, the BBC and Sky Movies, and as a professor of science communication at the University of Glamorgan in Wales. He has written many books, of which *The Science of James Bond* was published earlier in 2020.

https://markbrake.org

Adjusted for inflation, Bond is the highest-grossing movie franchise of all time (and the first saga to reach $10 billion of grossing; for more data see IMDB):

1. JAMES BOND
2. STAR WARS
3. MARVEL CINEMATIC UNIVERSE
4. HARRY POTTER
5. THE LORD OF THE RINGS
6. BATMAN
7. JURASSIC PARK
8. SPIDER-MAN
9. PIRATES OF THE CARIBBEAN
10. X-MEN



THE SCIENCE OF THE VERY SMALL HAS ENORMOUS POTENTIAL

DR WOUTER DECONINCK, BASED AT THE **UNIVERSITY OF MANITOBA** IN CANADA, IS PART OF THE TEAM WORKING ON THE ELECTRON-ION COLLIDER. ONCE BUILT, THE MACHINE WILL BE ABLE TO LOOK INSIDE THE ATOMIC NUCLEUS, ITS PROTONS AND NEUTRONS, AND HELP TO POWER THE TECHNOLOGIES OF THE FUTURE

TALK LIKE A SUBATOMIC PHYSICIST

PARTICLE ACCELERATOR
A machine that uses electromagnetic fields to propel charged particles to very high speeds and energies

PARTICLE COLLIDER
A type of particle accelerator that accelerates two beams of particles and lets them impact on one another

ELECTRONS
Subatomic particles that orbit the nucleus of an atom

NUCLEUS
The small, dense region consisting of protons and neutrons at the centre of an atom

PROTONS
Subatomic particles with a positive charge that are found in the atomic nucleus

NEUTRONS
Subatomic particles with no electric charge and a mass slightly greater than that of a proton

IONS
A charged atom or molecule

QUARK
An elementary particle inside protons and neutrons that is a fundamental constituent of matter

GLUONS
An elementary particle that acts as the exchange particle for the strong force between quarks

SUPERCONDUCTING MAGNETS
An electromagnet made from coils of superconducting wire that must be cooled to cryogenic temperatures during operation

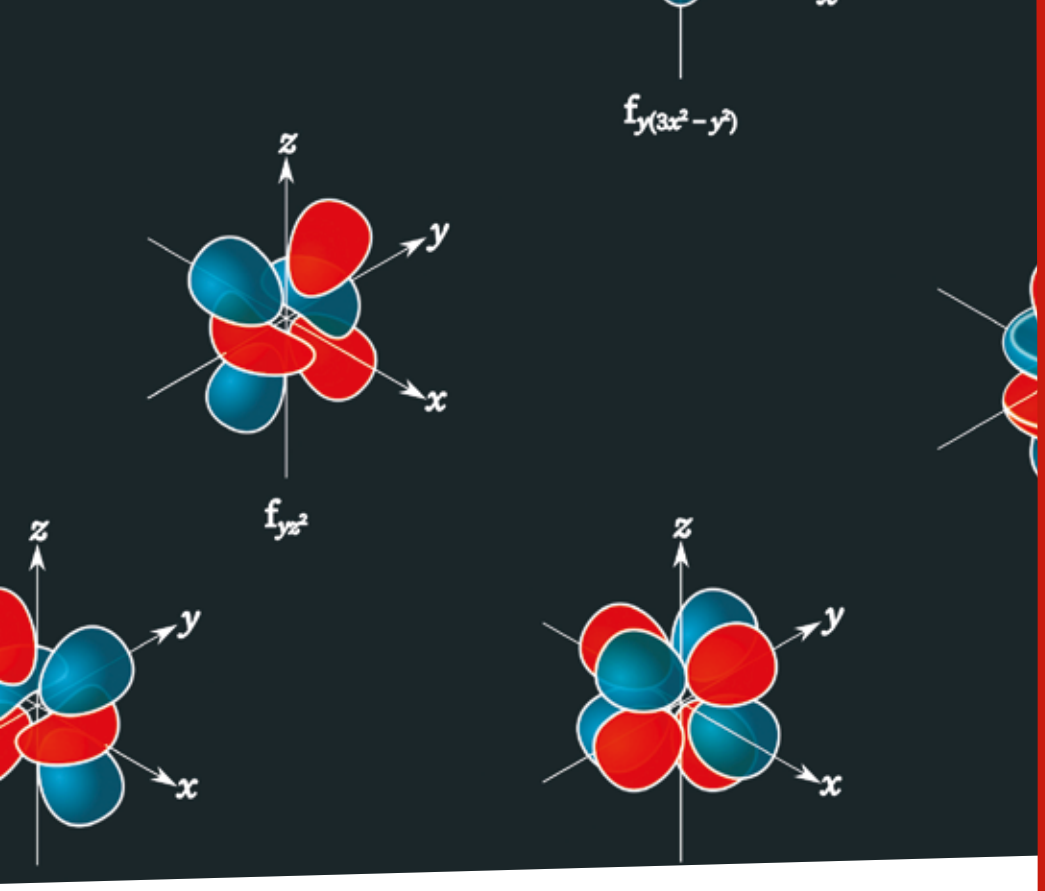
Subatomic physicists are interested in understanding exactly what is happening at inconceivably small scales. For instance, researchers might work to study protons, ions and nuclei in much the same way as a biologist might study the structure of a leaf. To achieve this, a biologist will use a microscope to magnify the subject of their investigations. However, while the cells that compose a leaf are small, protons, ions and nuclei are even smaller, so studying the structures of an atom requires machinery that is far more complex than a microscope.

Observing things at these scales requires the use of light, but rather than using visible light we might get from a light bulb, scientists have to use particle accelerator beams. Instead of optical lenses, which direct light into a human's eye, subatomic physicists use magnets, which focus the particles onto particle detectors. Performing this function requires a particle accelerator, of which there are very few in the world. One of the most notable was the HERA accelerator in Germany, which ran for 15 years (up to 2007) and was the world's most precise electron microscope.

Although the data gathered from HERA are still being used for particle physics experiments, there is a need to develop and build a new particle accelerator. Dr Wouter Deconinck, based at the University of Manitoba in Canada, is currently working on a new particle accelerator that will shed some light on the inner workings of atoms.

WHAT MAKES THIS NEW PARTICLE ACCELERATOR SPECIAL?

The accelerator is called the Electron-Ion Collider (EIC) and will be the only functioning electron-proton collider once it has been completed (the only previous one was the aforementioned HERA accelerator). EIC will use very intense polarised beams to allow scientists to make precise measurements at the atomic scale. Advances in accelerator technology mean that electron-proton collisions can be created, collisions which are 100 times as bright as the collisions that were previously made at the HERA collider! EIC will be able to ensure that bunches of particles in two colliding beams can rotate in the right way to be perfectly overlapping when they are at the interacting point.



© Wendy Nelson

DR WOUTER DECONINCK

Associate Professor, Department of Physics and Astronomy, University of Manitoba, Canada.

FIELD OF RESEARCH

Subatomic Physics

RESEARCH

Wouter is one of the members of the Electron-Ion Collider's software working groups. His research is concerned with ensuring that the software developed for the particle accelerator will still be functional and usable until at least 2040.

FUNDERS

Natural Sciences and Engineering Research Council of Canada (NSERC), United States Department of Energy (DOE), Brookhaven National Laboratory (BNL) and Jefferson Lab (JLab).

This material is based upon work supported by the Natural Sciences and Engineering Research Council of Canada (NSERC) and by the National Science Foundation under Grant No. 1714792.

WHAT IS WOUTER'S ROLE IN THE PROJECT?

When Wouter was at graduate school, he actually worked at the HERA accelerator, studying measurements of the polarisation of electron beams, so he has extensive experience working in this field. During the years that EIC has been designed and developed, Wouter has expanded his research focus to include physics processes that rely on precise polarisation measurements. "I am interested in so-called precision electroweak observables, which are very precise measurements that typically rely on polarised beams and which are sensitive to the indirect effects of new particles," explains Wouter. "Since particle physics produces large amounts of data that are analysed by large groups of scientists, we have to think carefully about the design of our analysis software." Wouter is, therefore, one of the members of the EIC software working group which tries to make sure that the software that is being developed for the accelerator will still be functioning until at least 2040.

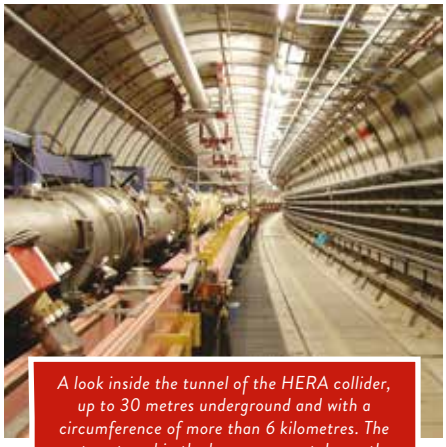
HOW WILL THE EIC PROJECT REVOLUTIONISE OUR UNDERSTANDING?

EIC will, for the first time, enable scientists to build a collider where both the electron and the proton can be polarised; the intensity of the collisions will be so high that specific studies of the proton structure will be possible. It will also be the first collider where electrons can collide with polarised ions such as deuterium or helium. "What we hope to achieve with the EIC is 'tomography' of the proton. Think of a medical scan (MRI or CT), but now apply that to a proton: we will be able to look at slices of the proton, both along the beam direction and in the direction transverse to beam direction," says Wouter. "We will even be able to look at the impact of the polarisation on these pictures. Finally, because we can accelerate ions, which also contain neutrons, we are not limited to studying the proton, but we can study the neutron just as well."

WHAT ARE WOUTER'S HOPES AND EXPECTATIONS FOR THE PROJECT?

Wouter is most excited about the prospect of measuring the electroweak mixing angle, which is a fundamental property of the weak force that can describe, for example, the beta decay of radioactive nuclei. It is the least familiar of the four fundamental forces, so the potential for developing new knowledge is enormous. Particle accelerators are used in a wide range of fields, such as cancer therapies or implanting ions into the chips in smartphones. "While nuclear and particle physics research aims to answer big questions about the universe, it is also the perfect training ground for future inventors of new technologies, or cures to diseases," explains Wouter. "I hope that among the hundreds of students who will work on EIC there will be many who go on to build the innovations of the future, whether they are potential cures to cancer, new medical imaging techniques, or even the next generation of the internet."

So, if you are interested in becoming part of the next generation, making a real difference to the world in which we live, subatomic physics might be your calling!



A look inside the tunnel of the HERA collider, up to 30 metres underground and with a circumference of more than 6 kilometres. The protons travel in the large vacuum tube on the left, while the electrons travel in the smaller one underneath.

ABOUT SUBATOMIC PHYSICS

Subatomic physics is the science of the small. The very small. Atoms are the smallest unit of matter that form chemical elements, typically measuring around 100 picometres across. To put that in context, one picometre is one trillionth of a metre – you would be able to get billions of them onto the head of a pin, although quite why you would want to is another matter!

WHAT IS REWARDING AND CHALLENGING ABOUT PHYSICS?

Of course, as with any branch of physics, the language of mathematics is of paramount importance. Many concepts within physics are beautiful and elegant, but without mathematics they cannot be properly expressed. "It takes a special skill to explain these concepts clearly to a broad audience, but it takes many years of practice to be able to come up with the right analogies and have them ready when someone on the bus asks what your work is about," explains Wouter. "I wish we did a much better job at explaining these concepts clearly and without mathematics, and I hope that we are training the next generation of physicists to do just that."

Perhaps you could be the one to drive this new way of thinking!

HOW IMPORTANT IS COLLABORATION WITHIN THE FIELD?

Collaboration is crucial. It takes a broad range of skillsets to advance any concepts within physics, irrespective of whether they are at the small or large scale. Subatomic particle accelerators are incredibly complex machines which are too large to be constructed by individuals or even small teams. The coronavirus pandemic has made meeting up more difficult, but Wouter and his colleagues spend several hours per week in video conferences with other scientists from different time zones. While this level of collaboration can be daunting, it is also exciting; ultimately, you are meeting people from around the world who are all working towards a common goal.

WHAT ATTRIBUTES HAVE MADE WOUTER A SUCCESSFUL PHYSICIST?

Wouter sees himself as an optimist; instead of finding reasons why an idea will not work and giving up, he is more likely to focus on the reasons why an idea is exciting and how best to make it work. "Research requires optimism – even successful physicists have to deal with broken equipment, changing schedules, and the rejections from funding agencies or prestigious journals where we like to publish our research papers," says Wouter. "I find that the best way to deal with this is to keep looking forward and to only look back when it helps you do better in the future."

HOW TO BECOME A SUBATOMIC PHYSICIST

• CERN is one of the most famous laboratories in the world and is home to a unique range of particle accelerator facilities: https://home.cern/

Their website has a page dedicated to subatomic particles which provides a wealth of information on the smallest building blocks of matter: https://home.cern/science/physics/subatomic particles

• Phys.org is an exhaustive resource for those interested in physics, with pages dedicated to a whole host of subjects related to physics. This article on subatomic particles shows how scientists continue to improve current understanding of the field: https://phys.org/news/2018-10-physicist-discovery-recasts-lifetime-hierarchy.html

• The average salary for a physicist in the US is around US$122,850 per year, with starting salaries beginning at around US$62,000 per year.

PATHWAY FROM SCHOOL TO SUBATOMIC PHYSICS

Wouter says that physics – and subatomic physics – is built on the language of mathematics, especially calculus. Thus, it is important to study calculus to gain a solid basis for most physics. "Once you have started college physics courses, you should study quantum mechanics. In subatomic physics we study the smallest particles, and these are described by the theory of quantum mechanics, developed in the 1920s," explains Wouter. "The other important theoretical topic is quantum field theory, a special kind of quantum mechanics, developed over several decades around the 1950s. Quantum field theory is necessary to describe particles like the Higgs boson. Overall, quantum field theory spans from the 1930s, with contributions from English theoretical physicist Paul Dirac, to the 1970s, when quantum chromodynamics was developed. "

2 or 3 A levels, or equivalent, including maths and physics.

You'll need a degree in a relevant subject for postgraduate study, such as maths, physics or a related science or engineering subject.

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

HOW DID WOUTER BECOME A PHYSICIST?

WHAT WERE YOUR INTERESTS AS A CHILD?

As a kid, I was enormously interested in astronomy. When I was 12 years old, I joined a youth astronomy club in my hometown. The club had a few telescopes and we would meet on Friday evenings, when the sky was clear, to observe far-away galaxies, count shooting stars, or measure the pulses of artificial satellites flying overhead. It is amazing how much science you can do with simple equipment. But not everything was science when I was growing up! I was in a swim club as well, so several nights a week I was in the pool and, on many weekends, I would be at competitions.

IF YOU WEREN'T A PHYSICIST, WHAT WOULD YOU BE DOING?

I was not always a physicist. I studied and graduated as an engineer before I switched to physics and started my research career. OK, some might argue that's not very different, but typical careers in engineering would not involve as much research or open-ended questions, but more trying to find solutions to problems on a shorter time scale. If I had stayed in engineering, I would likely be working on electronics or sensors systems in a company somewhere. Right now, I am also helping new start-ups with their science and technology ideas, similar to what an engineer would do. What do all these have in common? They are all about inventing new solutions to important problems!

WHO OR WHAT HAS INSPIRED YOU IN YOUR CAREER?

There are many role models in physics, but the people who inspired me the most (in college and before) were slightly older students who came a few years before me and were already at the next stage in their career. For example, when I was in college, we would have graduate students give talks about their work. Their talks are what convinced me to go into a research career myself, not reading about Albert Einstein or Marie Curie. Every time I talk to younger students, I try to make sure that they know that there are millions of scientific researchers in the world, all of whom (almost by definition) are working on unanswered questions using unique approaches that only they are the experts on. All of them enjoy their work because of the excitement that comes with being the first to discover something, no matter whether it will get them a Nobel Prize or not.

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

Outside of work, I enjoy going for walks, hanging out with friends, or watching a television show at home. Together with my partner, we brew our own beer and kombucha (a non-alcoholic fermented tea), a new batch every month or so. Brewing fermented beverages is a little bit like turning cooking into a science experiment. You have to be very careful to control what goes into the process so as not to contaminate anything. Then you just cross your fingers and hope that nothing goes wrong during the two weeks of fermentation! Based on the result, you can then tweak the recipe and start again on the next batch.

HOW DO YOU OVERCOME OBSTACLES IN YOUR WORK?

I find that the best way to get over obstacles is to just go for a walk! When I am out walking with our little dog, Brutus, it helps clear my mind. Then, when I get back to work, I will find a way around the obstacle. Taking a step back from work is often the best way of overcoming challenges.

WOUTER'S TOP TIPS

1. If you do not understand something, then ask questions! Many people see questions as a sign of weakness, but this is not the case at all. Having said that, if you think you can find the answer to a problem yourself, then you should certainly try doing so!

2. There is an old saying that goes, "If at first you don't succeed, try and try again." This is a sentiment I hold dear. Never give up – the sense of achievement you will feel if you manage to overcome a challenge will make it all worthwhile.

3. Your peers and tutors are a valuable source of support and assistance. If you find you are stuck on something, then ask for the help of others. You will generally find that people are happy to help.

Wouter with a group of summer undergraduate students on a tour of the particle detectors at Jefferson Lab. You can also start to do research at particle accelerators through summer research programmes for high school students and beyond.

MECH-ING ENDOSCOPIES SAFER BY USING ROBOTS YOU CAN SWALLOW

DR MARK RENTSCHLER, BASED AT THE **UNIVERSITY OF COLORADO BOULDER** IN THE US, LEADS A TEAM FOCUSED ON DEVELOPING MOBILE ROBOTIC CAPSULE ENDOSCOPES. THESE ROBOTS COULD IMPROVE PROCEDURES FOR PATIENTS AND SAVE LIVES

The digestive system is a long, twisting tube that runs from the mouth to the anus. It is composed of a range of hollow organs, such as the stomach, small intestine and large intestine, and solid organs, such as the liver, pancreas and gallbladder. There are three main functions of this system – transporting, digesting and absorbing food – and any problems with either of these can be fatal.

Indeed, one of the most prominent diseases of the digestive system is colorectal cancer, which is the third most commonly occurring cancer in men and the second most commonly occurring cancer in women. Given that incidence of this terrible disease is on the rise, researchers have turned their attention to developing ways of improving treatments which could benefit both the patient and the physicians treating it.

Dr Mark Rentschler, based within the Advanced Medical Technologies Laboratory, College of Engineering and Applied Science at the University of Colorado Boulder in the US, leads a team that has a vision to create capsule robots that patients can swallow. The ultimate aim is that surgical procedures can one day be performed autonomously on patients in the comfort of their own home.

WHAT HAS MARK'S TEAM BEEN WORKING ON?

Over the past ten years, Mark and the team have been developing the Endoculus, which is a robotic capsule endoscope that gastroenterologists can use to target the colon and the small bowel. Part of the problem with treating colon cancer is the environment of the gastrointestinal tract (GI). "Imagine driving a car inside a cave – you have no lights, no roadside signs and no GPS. Imagine that there is no pavement and that the ground is soft and moving and that there are puddles the size of your car throughout the cave. Imagine further that the walls are moving and can squeeze against your car," says Mark. "This is the gastrointestinal environment that the Endoculus must navigate!"

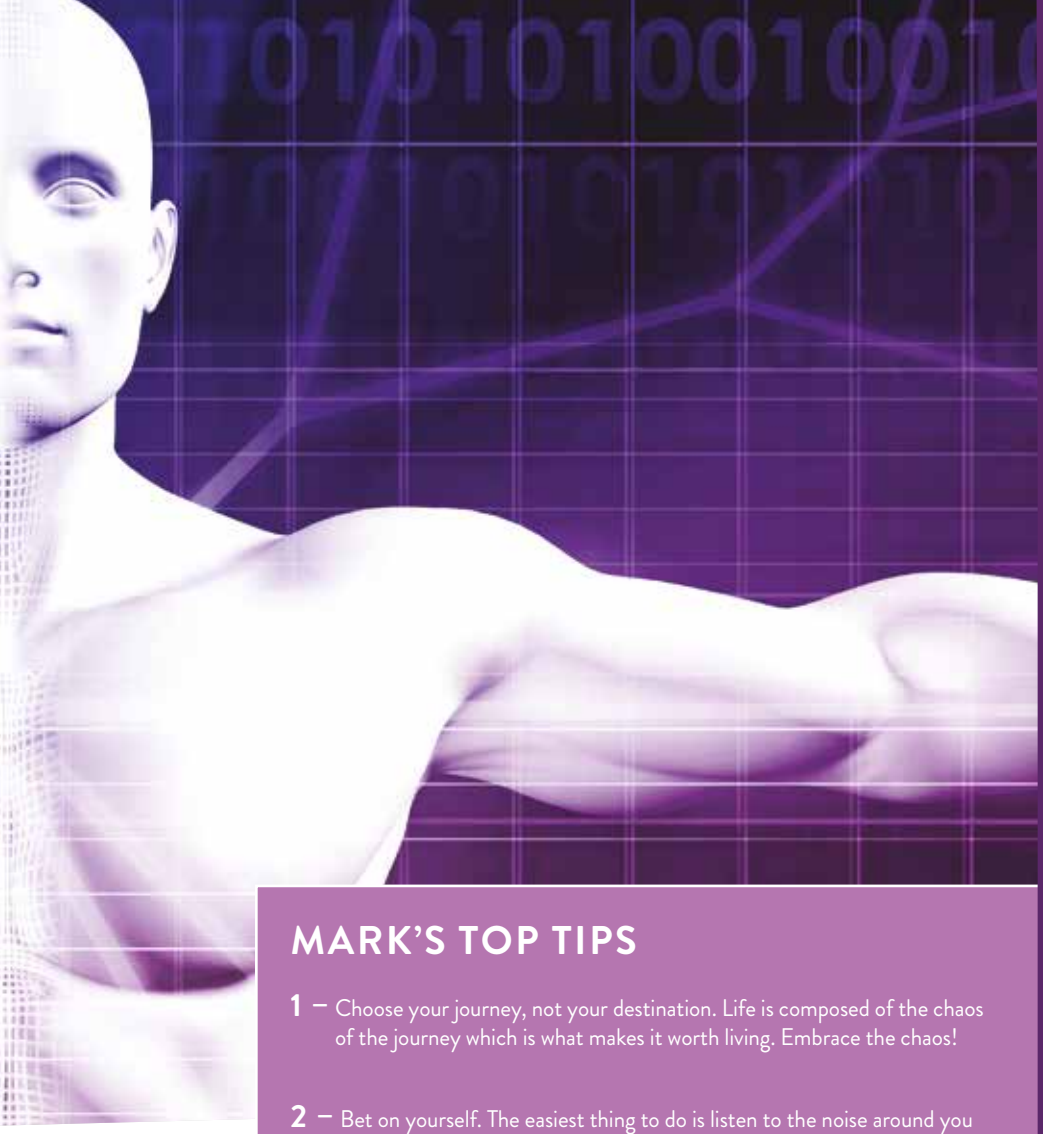
The Endoculus includes a vision camera, sensors to measure motor and robot position, an inertial measurement unit, current sensor to measure the current being sent to the robot, and a magnetic tracking sensor to track the position of the robot in three dimensions. The robot also has onboard lighting and a working channel for external tool access.

WHAT DESIGN FEATURES AFFECT THE MOVEMENT OF THE ENDOCULUS?

Of course, designing a robot that can move inside the body without damaging tissue is a significant challenge. To overcome this, the team has pioneered an approach that uses micro-patterned materials to penetrate through the mucus lining and grip the tissue without damaging it. The Endoculus is curved so it can move along the GI tract with little resistance and is designed to be wider than it is tall, making the platform more stable and improving visualisation from the camera. Because the robot is symmetric, if it flips over it can still function properly, and the camera image flips automatically so that the view remains the same throughout the procedure.

HOW IS THE ENDOCULUS SAFER THAN TRADITIONAL ENDOSCOPES?

Conventional endoscopes advance through



DR MARK RENTSCHLER

Advanced Medical Technologies Laboratory, College of Engineering and Applied Science, University of Colorado Boulder, USA.

FIELD OF RESEARCH

Mechanical Engineering

RESEARCH PROJECT

Mark's team is developing mobile robotic capsule endoscopes to explore the digestive system. The robots could improve procedures for patients and physicians.

FUNDERS

National Science Foundation, National Institutes of Health, Conmed Electrosurgery, Medtronic, Children's Hospital Colorado, and Colorado Office of Economic Development and International Trade

MARK'S TOP TIPS

1 – Choose your journey, not your destination. Life is composed of the chaos of the journey which is what makes it worth living. Embrace the chaos!

2 – Bet on yourself. The easiest thing to do is listen to the noise around you that may be telling you that you can't do it. You can do it. Sooner or later in life, people almost always realise they should be betting on themselves. Unfortunately, this understanding can come too late for some.

3 – You will move in the direction of the people that you associate with, so it's important to associate with people that are better than yourself. The friends you have will form you as you go through life. Make some good friends, keep them for the rest of your life, but make sure they are people you admire as well as like.

the GI tract by being pushed forward by a physician, but this is problematic because it is similar to pushing a rope at the same time as trying to steer it. "In an endoscopy, the endoscope slides against the GI tract and in some cases only changes course after the tract wall pushes back," explains Mark. "The Endoculus is designed to actively 'pull' itself forward which prevents any of the buckling or looping that can occur with a traditional endoscope." Ultimately, the Endoculus is designed to prevent the discomfort and pain associated with a push endoscopy.

WHAT STAGE IS THE PROJECT AT NOW?

The team is currently working on commercialising the project so that it might one day be used in hospitals. The design still needs some refining in order to ensure it is cost effective. To move forward with the research requires a level of business acumen that is not always considered when the focus is on the scientific feasibility of a product. Fortunately, the team has experience making the transition from bench to bedside with other projects, so they are well versed in what is required to make the Endoculus a reality in the future.

WHEN WILL THE TECHNOLOGY BE USED IN HOSPITALS?

Mark and the team expect the Endoculus (or variations of it) to be used in hospitals within five years. "Medicine is moving towards automation and 'smart health' on a number of fronts. Ultimately, data-driven approaches will become more common place to better treat the patient," explains Mark. "A portion of this is patient-specific medicine and a portion of this is the incorporation of machine learning and early artificial intelligence to help guide physicians."

Such approaches help highlight potential treatment options that might otherwise be overlooked by a medical team and so, while the Endoculus might take a while to reach the bedside, the principles behind it – automation and image-guided diagnosis – will arrive much sooner.

ABOUT MECHANICAL ENGINEERING

As the name suggests, mechanical engineering is a branch of engineering that is primarily concerned with analysing, designing and manufacturing mechanical systems. It combines physics, engineering, mathematics and materials science, and uses the principles of motion, energy and force. Mechanical engineering has a long history (it is one of the oldest branches of engineering), with the invention of the steam engine during the Industrial Revolution highlighting the significance of developing machinery.

WHAT IS REWARDING AND CHALLENGING ABOUT MECHANICAL ENGINEERING?

Mark says that he agrees with the notion that mechanical engineers seek to master the forces that drive our world. "I see mechanical engineering as an incredible challenge and an incredible opportunity," says Mark. "To understand and leverage the physics of nature to positively impact society is my career passion. My background in mechanical engineering, tied with my experience in medical devices, allows me to help make a positive impact for patients and physicians – I find this extremely rewarding."

WHAT TYPES OF COLLABORATION ARE REQUIRED IN THE FIELD?

Mechanical engineering is a highly interdisciplinary field and achieving goals requires a combination of a range of disciplines, such as computer science, electronics, and medicine in Mark's case. "The multidisciplinary aspect means that myself and those in my group have had to learn to cross disciplines to effectively communicate with such diverse teams. Ten years ago, crossing disciplines in these approaches was an effective research approach. Today, it is an absolute necessity," explains Mark. "While my background and scientific training will always be in mechanical engineering, I have developed knowledge in electronics, computer science, and a number of aspects of medicine including multiple fields of surgery and gastroenterology."

If you want to become a successful mechanical engineer, you will undoubtedly have to bridge several scientific fields and expand your skillset continuously.

WHAT ARE THE MAIN ISSUES FACING TODAY'S MECHANICAL ENGINEERS?

As Mark's research shows, mechanical engineering has found applications within medicine, but it also has relevance to renewables, conservation and technologies across micro and nano scales. "Mechanical engineers have been described as generalists, which is in many ways accurate. However, there is a fundamental aspect that well-trained mechanical engineers have and that is a deep-rooted understanding of the application of physics properties to create novel solutions," says Mark. "Mechanical engineers are trained to design, build and test mechanical components and systems. The trick to being successful today is to marry that understanding with a dose of electronics knowledge or coding expertise. This allows mechanical engineers to cross boundaries in a way some other disciplines cannot."

HOW TO BECOME A MECHANICAL ENGINEER

- The Institution of Mechanical Engineers is attempting to improve the world through engineering. The website is incredibly detailed and includes lots of information, including how to get involved in the field and career considerations: **https://www.imeche.org/**
- The American Society of Mechanical Engineers promotes the art, science and practice of multidisciplinary engineering and allied sciences around the globe: **https://www.asme.org/**
- Entry level mechanical engineers can earn anywhere between $55,000 to $75,000 depending on their level of experience.

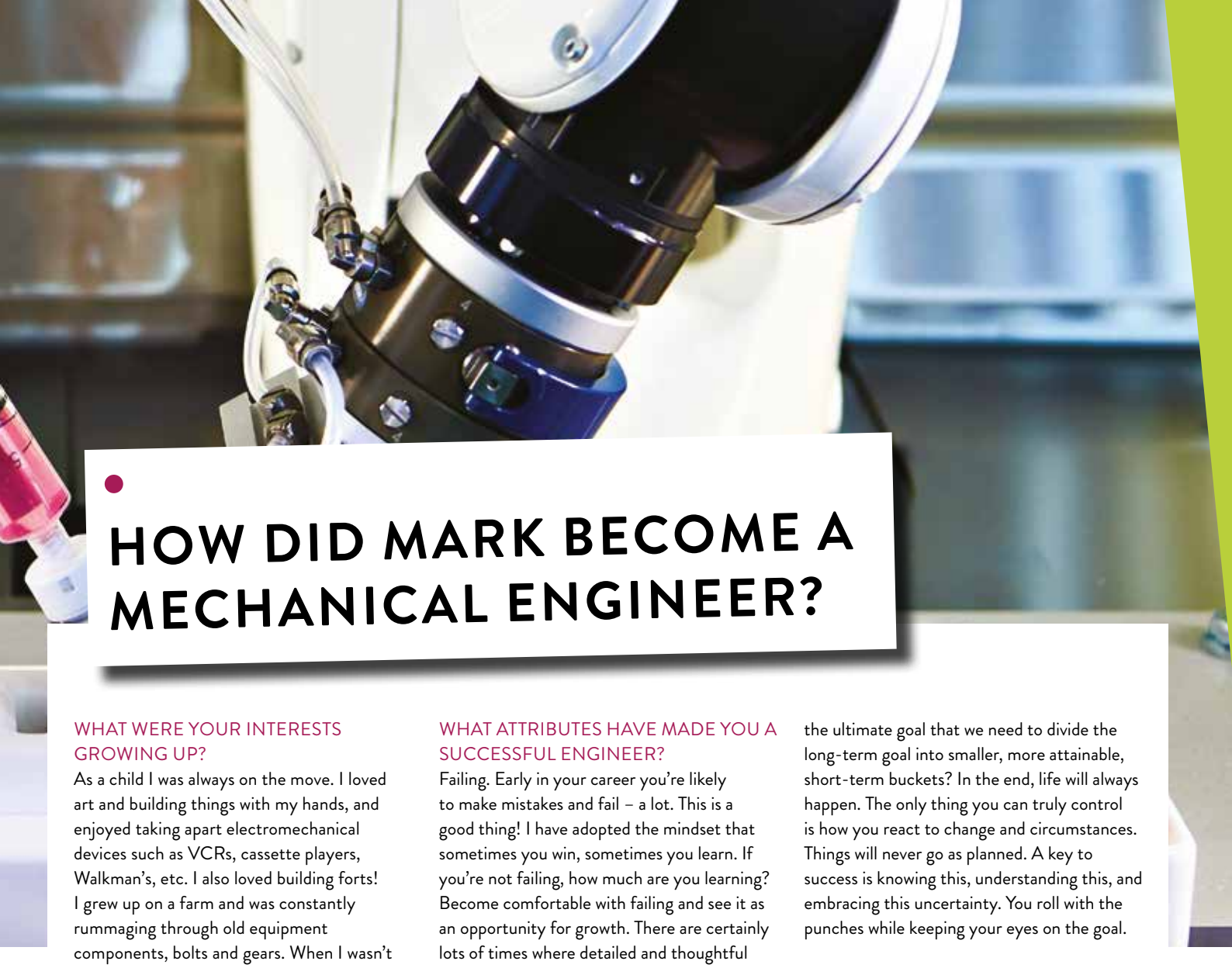
PATHWAY FROM SCHOOL TO MECHANICAL ENGINEERING

Mark believes that to be successful in mechanical engineering, a fundamental understanding of physics is essential, with mathematical concepts a close second. He is also a passionate advocate for creativity. "I recommend you develop your creative side in any medium that speaks to you, whether that is music, art, sculpture, dance, or doing something creative with your hands," says Mark. "Everything in our world has been built from a design created by an engineer. Understanding how to build things is a skill that can be honed in your free time through hands-on activities."

2 or 3 A levels, or equivalent, including maths and physics.

You could do a degree in mechanical engineering, electromechanical engineering, mechatronics or engineering manufacturing, depending on the specific area you want to focus on. Some courses include a year working in industry.

https://nationalcareers.service.gov.uk/job-profiles/mechanical-engineer



HOW DID MARK BECOME A MECHANICAL ENGINEER?

WHAT WERE YOUR INTERESTS GROWING UP?

As a child I was always on the move. I loved art and building things with my hands, and enjoyed taking apart electromechanical devices such as VCRs, cassette players, Walkman's, etc. I also loved building forts! I grew up on a farm and was constantly rummaging through old equipment components, bolts and gears. When I wasn't outside building things, I was inside working with LEGO to design, build and test new creations. I loved playing games with my siblings, riding my bike, and trying to design a garden that I didn't need to bend over to pull the weeds from. Every morning, I woke up with a desire to learn and build something new.

WHO OR WHAT HAS INSPIRED YOU IN YOUR CAREER?

As a child, I loved art and drawing but as I got older, I became interested in architecture and designing buildings. Ultimately, in high school I took courses in computer science and physics and began to learn about the field of engineering. I was also very much inspired by the notion of building a robot as a child. As I grew up, I began to put the pieces of the puzzle together to be able to design robotic devices and structures. For me, there wasn't a specific event or person that set me on this course. Instead, I tried a lot of different career paths through internships and research experiences that showed me what I liked and what I didn't. I got to where I am today by choosing opportunities that stretched me more than anything else.

WHAT ATTRIBUTES HAVE MADE YOU A SUCCESSFUL ENGINEER?

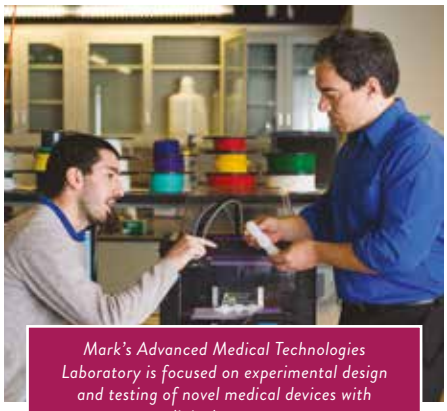
Failing. Early in your career you're likely to make mistakes and fail – a lot. This is a good thing! I have adopted the mindset that sometimes you win, sometimes you learn. If you're not failing, how much are you learning? Become comfortable with failing and see it as an opportunity for growth. There are certainly lots of times where detailed and thoughtful analysis is required, but at the end of the day, after the calculations are completed, you have to build it, test it, learn from it, and start again. One of the questions I ask students interviewing for a position in my lab is, "What is the last thing that you built?" I also ask, "When was the last time you failed?" Those that can answer these questions are those that I want to invest in. So, my willingness to try, fail, and try again have been central to my success.

HOW DO YOU OVERCOME OBSTACLES IN YOUR WORK?

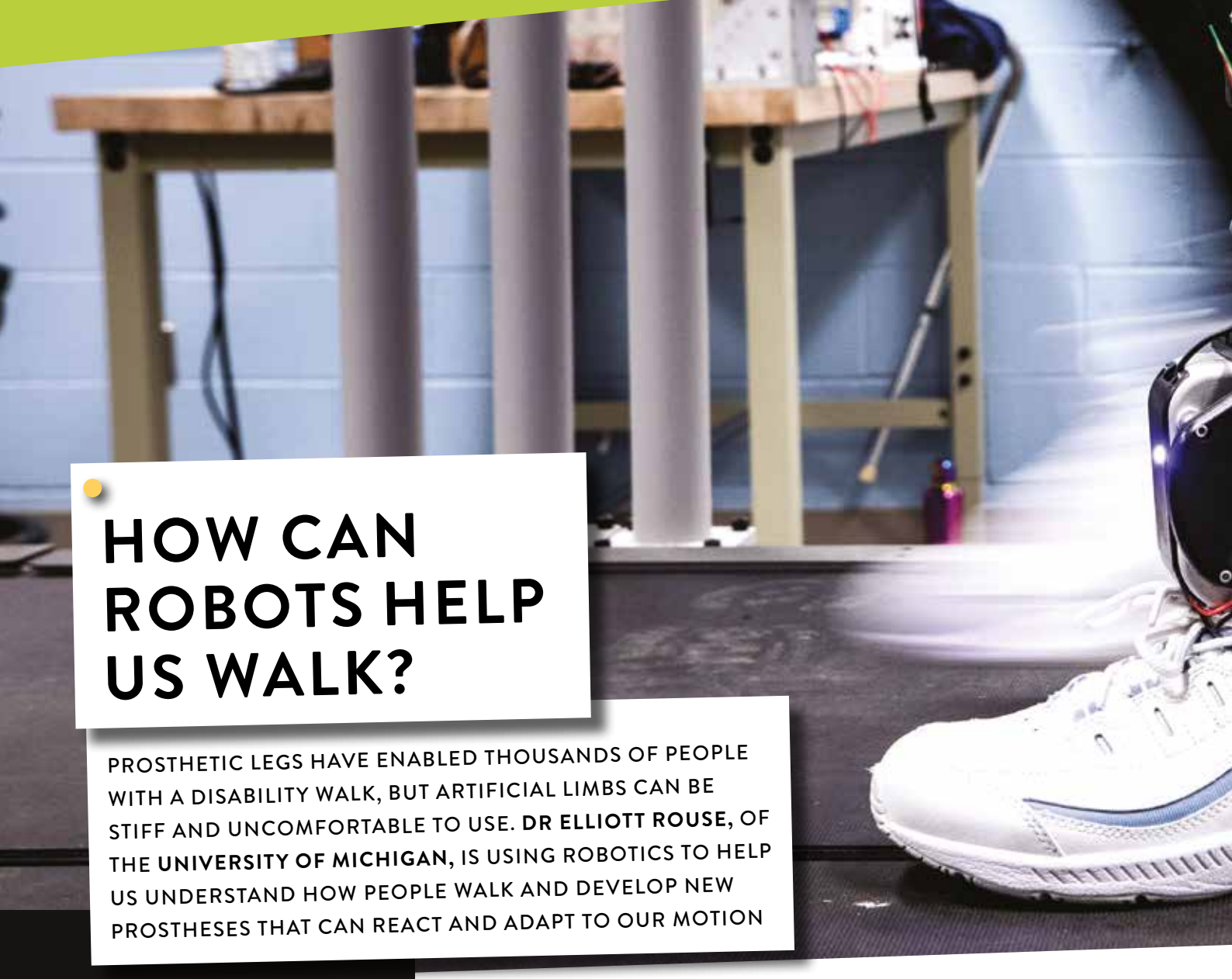
I am someone that is goal-oriented and entirely focused on what success looks like. One's definition of success in a project, career, and life will fundamentally shift the approach one takes to achieving that goal. In my work, if we're not able to achieve the goal we set for ourselves in the given timeframe, we need to pause and re-evaluate the goal and approach. Is the goal physically possible? If so, why did we fail? Did we pick the wrong path? Do we need additional members on the team? Did things not unfold as anticipated due to outside factors? Is there too much uncertainty between where we are today and the ultimate goal that we need to divide the long-term goal into smaller, more attainable, short-term buckets? In the end, life will always happen. The only thing you can truly control is how you react to change and circumstances. Things will never go as planned. A key to success is knowing this, understanding this, and embracing this uncertainty. You roll with the punches while keeping your eyes on the goal.

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

When I'm not at work I enjoy spending my time with my wife and kids. I also enjoy working out and staying in shape while I listen to podcasts on a range of topics from business, sports, leadership, marketing, and politics. There are many lessons to be learned from a variety of different points of view that are translatable to my responsibility as a parent and a spouse to those responsibilities I have in my day-to-day job. These various sources of 'down time' allow me to recharge away from the office.



Mark's Advanced Medical Technologies Laboratory is focused on experimental design and testing of novel medical devices with clinical partners.



HOW CAN ROBOTS HELP US WALK?

PROSTHETIC LEGS HAVE ENABLED THOUSANDS OF PEOPLE WITH A DISABILITY WALK, BUT ARTIFICIAL LIMBS CAN BE STIFF AND UNCOMFORTABLE TO USE. **DR ELLIOTT ROUSE,** OF THE **UNIVERSITY OF MICHIGAN,** IS USING ROBOTICS TO HELP US UNDERSTAND HOW PEOPLE WALK AND DEVELOP NEW PROSTHESES THAT CAN REACT AND ADAPT TO OUR MOTION

TALK LIKE A BIOMEDICAL ENGINEER

PROSTHESIS – an artificial body part

AMPUTATION – removal of a limb

BIONICS – the science of using ideas from biological systems to solve engineering problems. Bionic parts are artificial body parts that combine electronic and mechanical devices

BIOMECHANICS – the study of how living systems move and function

EXOSKELETON – in robotics, an exoskeleton is a wearable electromechanical device. They are often used to enhance performance, such as to help someone lift objects heavier than they normally could

LOCOMOTION – motions such as walking, running or climbing stairs

Robots make our lives easier in so many ways. For instance, they help us build cars, explore dangerous environments, and can even help us move our bodies. Iron Man might be a fictitious character, but bionic limbs that can adapt to different types of movement in the human body are an exciting new reality.

Dr Elliott Rouse is an assistant professor at the Neurobionics Lab in the University of Michigan in the US. He is also a biomedical and mechanical engineer whose pioneering research aims to help people with a disability and/or amputation. His Neurobionics Lab is devoted to overcoming many of the problems with conventional protheses and exoskeletons by understanding more about how we move and developing robotics technologies that leverage this.

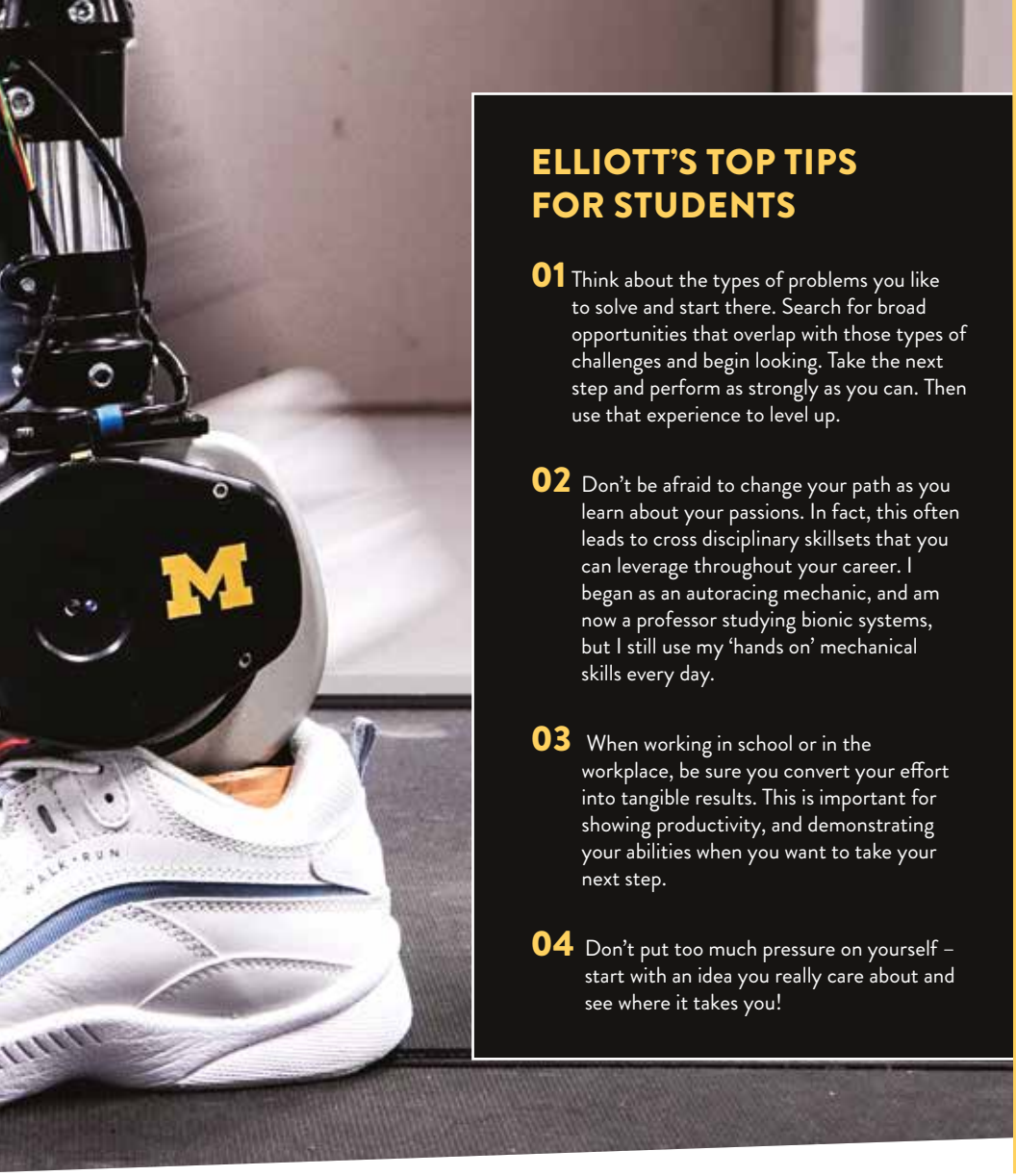
WHAT ARE THE PROBLEMS WITH PROTHESES?

Take a conventional prosthetic leg, for example. Leg prostheses have enabled many people who have lost part or all of their leg to regain the ability to walk without any need for crutches. Conventional prosthetic feet are usually made from carbon composite springs that store and return energy to push the wearer forward while walking. They are shaped like feet but are typically very stiff. This stiffness cannot be changed, which can be fine for walking but can make it more difficult if the wearer wants to do different kinds of activities, like moving from walking to running, or ascending and descending stairs.

When we walk, we burn energy from food to fuel the movement of our bodies. How much energy is needed to make a step depends on how efficient that conversion process is. If a protheses is poorly designed for a particular type of movement, the storage and return of energy in the carbon composite springs will also be poor, making the movement more tiring, in addition to more unstable and asymmetric.

WHAT DOES THE BIONIC LEG DO?

To solve these problems, Elliott and his team have developed an 'open source bionic leg'. This is a protheses that can be used as a bionic



ELLIOTT'S TOP TIPS FOR STUDENTS

01 Think about the types of problems you like to solve and start there. Search for broad opportunities that overlap with those types of challenges and begin looking. Take the next step and perform as strongly as you can. Then use that experience to level up.

02 Don't be afraid to change your path as you learn about your passions. In fact, this often leads to cross disciplinary skillsets that you can leverage throughout your career. I began as an autoracing mechanic, and am now a professor studying bionic systems, but I still use my 'hands on' mechanical skills every day.

03 When working in school or in the workplace, be sure you convert your effort into tangible results. This is important for showing productivity, and demonstrating your abilities when you want to take your next step.

04 Don't put too much pressure on yourself – start with an idea you really care about and see where it takes you!

DR ELLIOTT ROUSE

Assistant Professor
University of Michigan, USA

FIELD OF RESEARCH

Biomedical Engineering, Mechanical Engineering, Robotics

RESEARCH PROJECT

Using robotics to understand how humans walk and design better protheses

FUNDERS

National Science Foundation
National Institutes of Health
US Department of Defense
D Dan and Betty Kahn Foundation

knee or ankle joint, or both. It is freely available to the research community, i.e., open source. Unlike a normal protheses, Elliott's bionic leg is fully robotic and can be controlled using a small computer. Not only that but sensors in the leg give information about the forces at work, which scientists can use to understand how the joint behaves during different types of movement, and develop mathematical instructions called 'control systems' that tell the leg how to move.

Excitingly, many different research groups and students around the world have been involved in this project. Students from Georgia Tech, USA, and India have been writing new software to learn more from the data collected from the bionic leg. The leg has also been designed to be low-cost, compact and easy to manufacture, meaning it is easier for innovators to use it as a test device to trial their ideas.

Elliott has been using this bionic leg to better understand how humans walk and as a test system for designing new bionic protheses. Although many of us do not think about it when we walk, walking is a complicated movement and understanding the biomechanics of this process has challenged researchers for years. Through his research, Elliott realised that there is a longstanding misconception about how joint stiffness changes during walking.

WHAT ARE THE NEW DESIGNS?

Based on this new knowledge, Elliott and his team have developed a new type of ankle-foot protheses called the VSPA foot that can vary its stiffness from step to step. VSPA stands for variable stiffness prosthetic ankle-foot and walking with this VSPA foot should feel much more natural for the wearer when compared to conventional foot prostheses. Licensed by WillowWood, a major prostheses manufacturer in the US, it also heralds the development of more advanced protheses that can respond to changes in movement, just like our bodies do. These new protheses are much more flexible and efficient in terms of energy use, as well. Elliott is now working with a company to commercialise the VSPA foot and make it available to more people who need protheses.

Importantly, though, Elliott's work is already helping to increase our understanding of biomechanics and make a difference to the lives of people with amputation and others living with a disability. Elliott is also hoping to design new robotics technologies and exoskeletons for people who have had a stroke to assist them with their mobility.

"We seek to address fundamental questions about how the nervous system regulates leg mechanics during locomotion", explains Elliott. "To this end, we're essentially reverse-engineering the human neuromotor system, which lets us use this information as a set of instructions for developing transformative assistive technologies. We're also studying the science of human perception and the role of preference in the design and control of wearable robotic systems."

ABOUT BIOMEDICAL AND MECHANICAL ENGINEERING

According to the University of Michigan, biomedical engineering is, "the application of the life sciences and engineering principles to bridge the gap between medical technology and medicine in practice". Mechanical engineering, on the other hand, is, "the application of physical mechanics to build the technology of the future". Mechanical engineers design and build vital technologies from cars to planes, robots and prosthetics. Biomedical engineers use their expertise to develop medical technologies for all areas of patient care, from diagnostics to treatment and recovery.

Elliott's work is the perfect example of research at the cutting-edge of biomedical and mechanical engineering. He explains the meaning of neurobionics – the name of his lab – and what the future holds for these exciting fields.

"Neurobionics refers to my specific research group, rather than a discipline. It encompasses the idea of studying how the nervous system regulates the mechanics of gait [a particular way of walking] and using this information to develop innovative wearable robotic systems."

WHAT DOES THE FUTURE LOOK LIKE FOR BIOMECHANICAL SCIENCE?

It's a super exciting time for our lab and the field as a whole. Our work on the open source leg is being adopted by groups around the world. Our VSPA foot is being commercialised and may truly change the quality of life for people with leg amputations. We're advancing a new and potentially transformative approach for the design and control of exoskeletons and robotic prostheses based on user preference. Finally, we're studying people's ability to perceive changes in metabolic rate, and developing new and creative metrics of success for modern exoskeletons. Over the next several years, we'll continue to study these important areas, and will expand our approaches as we learn more about these topics.

WOULD YOU RECOMMEND A CAREER IN BIOMECHANICAL SCIENCE?

My answer is a resounding 'yes', but this industry is a little different than most. In the development of bionic systems, advanced research and design is generally conducted within academia and funded by government agencies. This is different from other areas of engineering, where research and development can be conducted primarily within companies. If someone is interested in this field, their best bet is to get involved in a laboratory at their university – this could be as a student, staff engineer, therapist or volunteer. There are many fantastic universities with great wearable robotics researchers, and most would be happy to learn of people who are interested in their work.

HOW TO BECOME A BIOMEDICAL OR MECHANICAL ENGINEER

There are several routes into biomedical and mechanical engineering, including apprenticeships, but the most common route is a degree at university. This is particularly important if you want to go into a research-based career like Elliott.

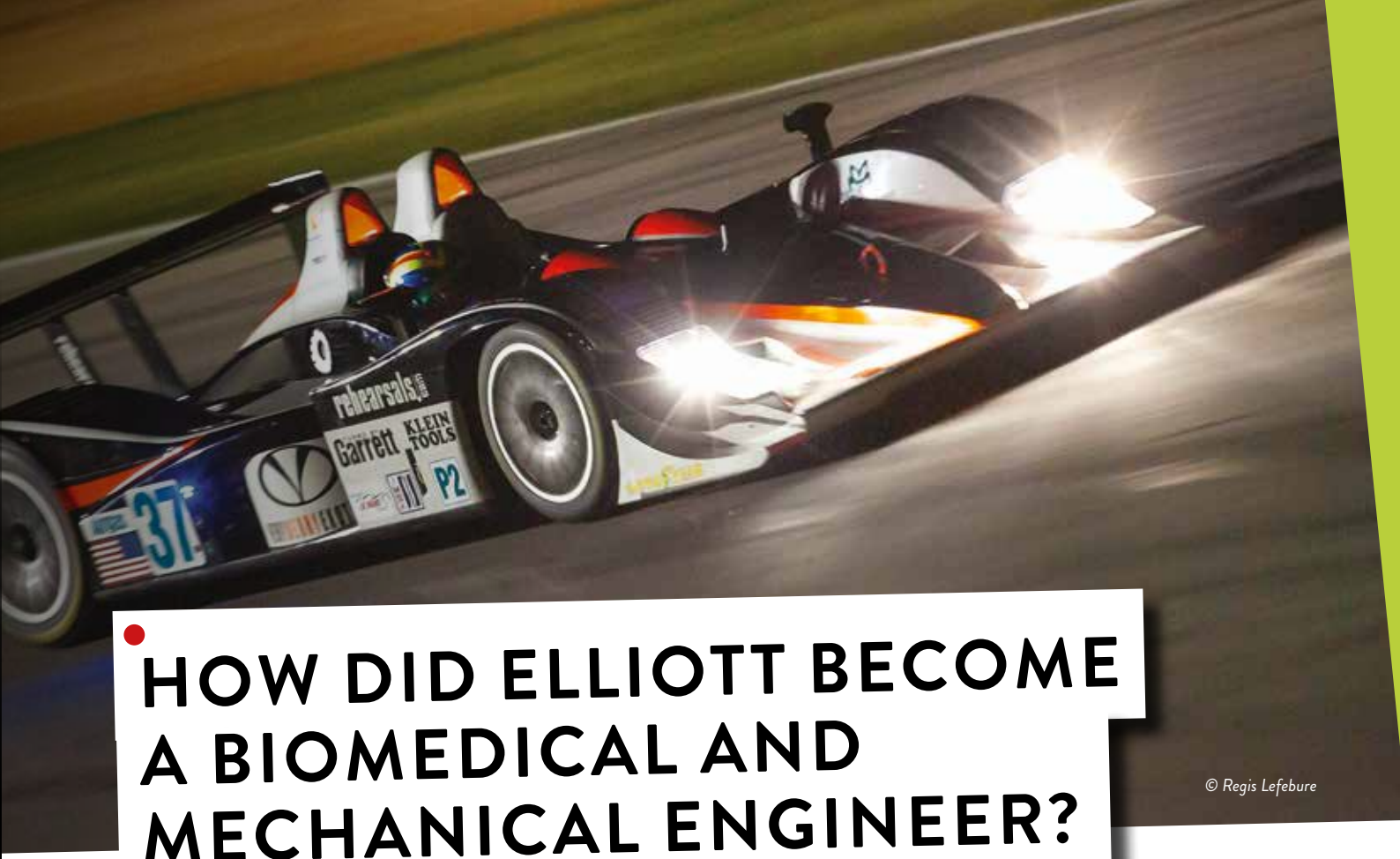
- Many labs are happy to host work experience students, so get in touch. For example, Elliott and his team have several projects listed in their website: **https://neurobionics.robotics.umich.edu**
- The University of Michigan lists a number of exciting engineering outreach opportunities on their website: **https://ceo.umich.edu**
- The average salary for a biomechanical engineer is $65,779, which can rise to an $80,000 or $100,000 starting salary with a doctorate

PATHWAY FROM SCHOOL TO BIOMEDICAL OR MECHANICAL ENGINEER

Elliott says, "At the high school level, I would say take advantage of calculus and advanced physics courses. If your school offers a robotics club, get involved. Tinker with things, learn to code and play with basic microprocessors (e.g. Arduino) and single board computers (e.g. Raspberry Pi). At the undergraduate level, personally, I'd recommend majoring in robotics or mechanical or electrical engineering. These degrees provide a little more technical depth."

Maths, physics, chemistry and engineering are recommended subjects for both biomedical and mechanical engineering.

More information about the different types of engineering degrees can be found here: **https://typesofengineeringdegrees.org**



© Regis Lefebure

HOW DID ELLIOTT BECOME A BIOMEDICAL AND MECHANICAL ENGINEER?

WHAT DID YOU WANT TO BE WHEN YOU WERE YOUNGER?

My career path during college provided a unique set of experiences that culminated in a passion for research and development of technologies to help people with disabilities. As an undergraduate student, I worked full time for a professional autoracing team. At that time, I thought this was the most amazing job possible but, as the years went on, I longed to make a greater impact on people, and particularly those with disabilities. So, the summer before my last year at university, I took a break from autoracing to join a summer internship programme at the Cleveland Clinic's biomedical research division, and I fell in love with biomedical research and development.

I then began researching graduate schools and remember seeing a press conference from Dr Todd Kuiken at Northwestern University/Rehabilitation Institute of Chicago. He had developed a surgery technique to re-wire people's nerves to control advanced prostheses, and I was really excited about the prospect of working with him. I got in contact with Dr Kuiken and was accepted onto the MS programme at Northwestern University. So began a long path to obtain a doctorate and eventually study technologies that will change peoples' lives.

WHO OR WHAT INSPIRED YOU TO GET INTO MECHANICAL ENGINEERING?

Honestly, I didn't know much about mechanical engineering when I went into my undergraduate studies. I pretty much chose mechanical engineering because my twin brother and friends were pursuing mechanical engineering, and I knew I was passionate about cars. When I began to study more advanced mathematics and physics, I was fascinated. The course that probably had the greatest effect on me was a class that studied system dynamics, which discussed the tools of modelling physical systems. Upon graduation, I realised I enjoyed system dynamics, and that I wanted my work to help people overcome physical challenges. Once I began looking into rehabilitation and biomechanics, I felt drawn to this area of study because it held the potential to impact people in the near term (which is uncommon in academic research), and because there are many important and challenging problems to solve.

WHAT DO YOU LOVE MOST ABOUT THE WORK YOU DO?

That is a tough question! There are three main things I love about what I do. 1) I love teaching and mentoring students. The world of engineering has so many interesting things to discuss, and it's wonderful to be able to share these concepts with bright young students. In addition, I care deeply for the graduate students I mentor in my research group and enjoy helping them grow personally and professionally. 2) I thrive on independence. I love being able to set the vision for my research group and study technical challenges I find most meaningful and interesting. And 3) I'm passionate about changing the lives of people in the near term, especially those with disabilities. There's something really special about when an experimental participant tries the technologies we develop, and they smile and discuss what they like and dislike, and how they could see their life changing. These experiences remind me of the meaning of our work and keep me refreshed; they are as fulfilling as they are energising.

WHAT DO YOU KNOW NOW THAT YOU WISH YOU'D KNOWN WHEN YOU WERE YOUNGER?

Oftentimes, undergraduate students will visit me and discuss their career situation as they determine their next step. Usually, they're anxious and sometimes feel lost. They seem to feel the pressure of finding the right thing to do with their life, and if they don't figure it out, they've somehow made a mistake or sabotaged themselves. I think that way of thinking about the future puts too much pressure on someone – life doesn't really work that way. I started with the idea that I enjoyed the study of system dynamics and wanted to help people. I recommend that students zoom out and think about what gets them excited. Begin there and search exciting options that they find meaningful.

THE SKY'S THE LIMIT: NEW HORIZONS FOR AEROSPACE

SCIENTISTS HAVE BEEN INSPIRED BY THE NATURAL WORLD SINCE TIME IMMEMORIAL. **PROFESSOR KRISTI MORGANSEN**, OF THE **UNIVERSITY OF WASHINGTON** IN THE US, IS COMBINING INSIGHTS FROM NATURE WITH TRADITIONAL ENGINEERING, DISCOVERING A WORLD OF NEW POTENTIAL FOR OUR FLYING MACHINES

TALK LIKE AN AEROSPACE ENGINEER

AERONAUTICS – the science of aircraft

AEROSPACE – the science of aircraft and spacecraft (i.e. aeronautics and astronautics)

AVIATION – the flying of an aircraft

SENSOR – a device (either biological or man-made) that detects or measures something about its environment

UNMANNED AERIAL VEHICLE (UAV) – an aircraft piloted by remote control or computers

The science of aviation and aerospace is constantly changing. In recent years, aerospace engineers have made big strides in developing more efficient aeroplanes, long-distance spacecraft, and intelligent drones, to name but a few. Such innovations require innovators. Professor Kristi Morgansen is a professor in the William E. Boeing Department of Aeronautics and Astronautics at the University of Washington, and is a pioneer of blue-sky thinking. By working with scientists from a wide range of disciplines, she is helping to push the limits of what aeronautics can achieve.

LOOKING TO NATURE

Humans have only been flying around for just over a century, but many animals have had it nailed for millennia. Birds, bats and insects all evolved flying mechanisms independently, and Kristi is intent on discovering how their methods could be applied to aeronautics. "Bio-inspired engineering is more exploratory and high-risk than traditional engineering," she says. "I find this 'try something crazy!' aspect really exciting."

Kristi takes a special interest in bats, the only mammals that can fly. "Bats are amazing! They essentially have a hand within their wing. There is a stretchy membrane beneath each 'finger' so they can dramatically change the shape of their wing as they're flying – they can do some incredible manoeuvres." This could have direct applications to aeronautics. As Kristi explains, "Aircraft are starting to use lighter materials, which makes them more energy-efficient but also more flexible. How do you control the shape of a flexible wing so it doesn't flutter or distort? The animal kingdom could help answer that."

Aircraft have already taken notes from nature. For instance, the little curved wing tips that you can see on aeroplanes is a feature seen in birds and bats. They help the wings to glide smoothly through the air and reduce drag. "I

PROFESSOR KRISTI MORGANSEN

William E. Boeing Department of Aeronautics and Astronautics, University of Washington, Seattle, USA

FIELD OF RESEARCH

Aeronautics and Astronautics

RESEARCH PROJECT

Focusing on sensory systems for flying vehicles, drawing inspiration from biology and neuroscience.

FUNDERS

Joint Center for Aerospace Technology Innovation
US Federal Aviation Authority
ONR grant numbers
N00014-10-1-0952 & N00014-17-1-2623
AFOSR grant number
FA9550-14-1-0398

work in exploring what might work," says Kristi. "Then, once the science has been established, traditional engineering methodology will take it from the design stage to a product."

DRONE DEVELOPMENTS

Drones have opened up a huge new range of possibilities, from package delivery to supporting disaster areas. "We have looked into using unmanned aerial vehicles (drones) for search and rescue, or to get emergency supplies to victims of disasters such as earthquakes," says Kristi. "The environments they find themselves in are often very complex – inner cities, for examples, can be full of obstacles – so developing effective sensors is a top priority."

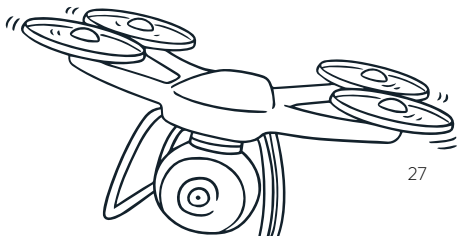
Kristi works with a company that is developing 'morphing vehicles'. This is a drone with four rotors on arms that can change length and angles as the drone flies. For instance, if one rotor fails, the arms can reconfigure and rebalance the drone so it can continue flying with three rotors. Having effective sensors that can detect such changes, and having systems that can respond to them as rapidly as possible, is essential for these to work.

Such complex arrangements draw on data science, which is another interest of Kristi's. "Sensors produce plenty of data, but how do we find it and how do we choose which data to use?" she asks. "This is especially true for autonomous vehicles that make their own decisions. We have to make sure the systems behave in the way we want them to."

THE NERVOUS SYSTEM: NATURE'S FINEST DATA PROCESSOR

Once again, the natural world can help with this. The way that animals sense the world around them and make decisions accordingly is of great interest to Kristi. Bats, for instance, can make decisions in a fraction of a second based on what sensors on their wings are telling them. "I work with biologists and neuroscientists. I love working with people from other fields," says Kristi. "We look at how animals' brains process information and how we can translate this to machines. There's a lot of interesting stuff happening!"

Of course, not everything in nature is directly applicable. Animals fly through flapping their wings, whereas aircraft function based on propulsion, for instance. "We're not trying to replicate flapping wings, because people would get very motion sick, not to mention other issues it would pose," says Kristi. "However, we are looking at ways that we can be more efficient with data processing, energy and computation. Sensors have a big role to play in this, and we hope to test our findings within commercial aircraft soon."



ABOUT AERONAUTICS AND ASTRONAUTICS

Aeronautics covers the science behind building and flying aircraft. Astronautics covers a similar field but for beyond the Earth's atmosphere – the science behind spacecraft and space exploration. Aerospace is a catch-all term that covers both. Through her interactions with other disciplines, Kristi's work goes beyond these straightforward definitions. She explains more about what her working life is like:

WHAT MOTIVATES YOU?

I don't really get bored. I like problem solving and I love the intersection between mathematics and engineering. I love coming up with a mathematical representation of something, predicting what this thing will do in the real world, and then demonstrating it. If it does work as expected, great – if it doesn't, I like to discover why. I love seeing the application of maths and physics – it never gets old!

WHAT CHALLENGES DO YOU FACE IN YOUR WORK?

There are only 24 hours in a day, which is annoying! The pandemic has also made it difficult to get into the lab. Working with different people can have its challenges, as people respond to different styles of communication. Managing a large group of people is also challenging, though this brings its own joys too. The days of scientists working on their own are long gone. The old-fashioned perception of engineers working alone has led to a lack of diversity and bias, which can only be changed through collaboration.

I think that attracting a broader range of people, including those from under-represented minorities, should be a key focus. Modern-day lifestyles should not be all about work, and we should accommodate this, otherwise we miss out on talented people. For instance, the pandemic has highlighted the challenge of childcare. We shouldn't expect people to work long hours every day, and the sector needs more flexibility in how we engage with people. We are making progress, but there is still a way to go.

WHAT IS YOUR KEY MESSAGE ABOUT YOUR WORK?

I am not at the beginning of my career. The sort of broad-scale work that I do is not always available for engineers at the start of their working life. But this does not mean it is unattainable; by building your skills as you go along, you can work towards securing your perfect role.

As an undergraduate, you learn the fundamentals of your subject and how to apply them. As a master's student, you go into more depth in your field, and then, for your PhD, you're looking for something novel. You keep progressing as your career progresses – that's what makes it so rewarding.

HOW TO BECOME AN AEROSPACE ENGINEER

- Investigate universities with aerospace engineering, aeronautics and astronautics programmes or mechanical engineering departments with aerospace programming.
- Enrol in a related engineering discipline at university and enter the field through an internship or specialised entry position with an aerospace company. Businesses such as BAE Systems, Airbus, Rolls-Royce, Messier-Dowty and Goodrich run aerospace apprenticeships, as do NASA, the European Space Agency (ESA) and Lockheed Martin.
- According to Career Explorer, the average salary for an aerospace engineer in the US is $110,000 per year.

PATHWAY FROM SCHOOL TO AEROSPACE ENGINEER

Kristi recommends taking mathematics as a priority. She also advocates computer science, highlighting the importance of programming within many disciplines. Physics is also required by many university courses, and other sciences are also useful.

Some university degrees specialise in aerospace engineering. Otherwise, degrees in electrical engineering, mechanical engineering, product engineering, software engineering, physics or mathematics can all lead to a career in this area.

KRISTI'S TOP TIPS FOR STUDENTS

01 Find mentors. People who can help you develop your technical, professional and interpersonal skills are invaluable. You can never have enough mentors!

02 Learn how to study. For many, it's not a natural thing, but it can be learned. It's not a case of 'you have it or you don't' – you can learn it and develop your stamina.

03 Find things that excite you. If you're not excited by it, don't pursue it!

HOW DID KRISTI BECOME AN AEROSPACE ENGINEER?

WHAT WERE YOUR INTERESTS AS A CHILD?

When I was young, I enjoyed tackling puzzles and solving problems. I liked being outdoors and loved reading. I became interested in space fairly early on, but I didn't know what direction that would take until much later.

WHAT INSPIRED YOUR CAREER PATH?

My eureka moment was during my undergraduate degree. My advisor had been working with me on the application of mathematics into physical systems, because he knew it was an area I was very interested in. He suggested I go to graduate school, which hadn't occurred to me until then. At that point, I started working in a robotics lab in a summer research programme and realised that this sort of science was what I wanted to do long-term.

WHAT ATTRIBUTES HAVE HELPED YOU BECOME SUCCESSFUL?

I'm pretty tenacious, and don't give up easily. This is useful as there are always obstacles within research. I like being creative and exploring things.

HOW DO YOU SPEND TIME OUTSIDE OF WORK?

It can be hard to switch off – one method I use is reading murder mysteries at night!

A wind tunnel is a test bed for airplane design, control and aerodynamics.

A high flexibility actuated wing, developed by the University of Washington and NASA, undergoing testing in a large wind tunnel.

Credit: Ulrich Münzer (2015).

HOW MICROBES IN ICELAND CAN TEACH US ABOUT POSSIBLE LIFE ON MARS

DR SOLANGE DUHAMEL AND DR **CHRISTOPHER HAMILTON**, BASED AT **THE UNIVERSITY OF ARIZONA**, HAVE BROUGHT TOGETHER THEIR RESPECTIVE EXPERTISE IN ENVIRONMENTAL MICROBIOLOGY AND PLANETARY SCIENCE TO INVESTIGATE HOW LIFE COULD SURVIVE ON MARS. FASCINATINGLY, THIS HAS BEEN DONE BY EXPLORING AN AREA IN ICELAND THAT RESEMBLES THE RED PLANET

When we think of astronauts, deep-sea exploration is not the first thing that springs to mind. Similarly, space walks are not usually associated with oceanographers. And yet, oceans are often used in the preparation for space exploration. For instance, lengthy dives in weighted diving suits mimic the Moon's low-gravity environment, and underwater research labs provide a practice setting for life on the International Space Station.

Nonetheless, the connection between our oceans and space can go far beyond space walking and deep-sea diving. Dr Solange Duhamel, an oceanographer, and Dr Christopher Hamilton, a planetary scientist, both based at the University of Arizona, have pooled their expertise in two very different disciplines to work on collaborative research projects in astrobiology, including investigations of hydrothermal systems in Iceland, to uncover what life in these extreme environments might reveal about life on Mars.

WHY DID SOLANGE AND CHRISTOPHER GO ON AN EXPEDITION TOGETHER?

Six months after the end of the 2014–2015 Holuhraun eruption in Iceland, Christopher led a team that studied the lava flow-field and observed a lava-induced hydrothermal system where the lava had entered a segment of the Jökulsá á Fjöllum river. However, the initial team did not include any biologists and so, Christopher invited Solange –an oceanographer and expert in environmental microbiology and biogeochemistry – to join them the following year. With Solange on board, the team returned to the field site to investigate the unusual forms of life that had developed within Holuhraun's hydrothermal systems.

Christopher is a planetary volcanologist and the Holuhraun eruption – which took place in a pristine part of the Iceland highlands – was immediately important as an analogue for Mars. In contrast, Solange is an oceanographer, with expertise in how life can thrive in extreme environments. Solange explains, "When I joined the expedition led by Christopher, the team was composed of geologists and planetary scientists – I was the only biologist. I brought new competences to the group and together we have been able to gather a complementary set of physical, chemical and biological data to characterise the ecology and biogeochemistry of the system at Holuhraun."

WHAT MAKES A TERRAIN, SUCH AS HOLUHRAUN, ANALOGOUS WITH MARS?

Holuhraun is located within a barren sand sheet in Icelandic highlands, between the Vatnajökull ice cap and the Askja central volcano. "This high-altitude location has very little vegetation and resembles the surface of Mars. Volcanic eruptions on Mars also tend to be larger than recent eruptions on Earth, but the 2014–2015 Holuhraun eruption generated the largest outpouring of lava in Iceland during the past 235 years," explains Christopher. "This makes the terrain similar to Martian lava flows."

WHAT HAVE THE LAVA-INDUCED HYDROTHERMAL SYSTEMS REVEALED ABOUT MARS?

Solange explains, "When the Holuhraun lava flow inundated a segment of the Jökulsá á Fjöllum river, it created unusual forms of hydrothermal activity. This was very exciting because those conditions could mimic those found on Mars in the past."

Given the extreme conditions on Mars, if there is life on the Red Planet, it must be adapted to extreme environments. On

DR SOLANGE DUHAMEL

Associate Professor, Molecular and Cellular Biology, College of Science, University of Arizona, USA.

FIELD OF RESEARCH

Environmental Microbiology, Biogeochemistry, Astrobiology and Oceanography

RESEARCH PROJECT

Solange is concerned with studying the role of microorganisms as agents of biogeochemical transformations, and how microbes adapt to different, often extreme, environments.

FUNDERS

National Science Foundation, The Gordon and Betty Moore Foundation

DR CHRISTOPHER HAMILTON

Associate Professor, Lunar and Planetary Laboratory, College of Science, University of Arizona, USA.

FIELD OF RESEARCH

Earth and Planetary Science

RESEARCH PROJECT

Christopher is the Principal Investigator of RAVEN, which will help pave the way for the next generation of robotic spacecraft on Mars. His research specialty relates to geological surface processes and planetary volcanology.

FUNDER

National Aeronautics and Space Administration (NASA)

Earth, thermophiles (organisms that thrive at high temperatures between 50°C and 122°C), may be among the oldest forms of life on the planet. With so many volcanoes on Mars, it is possible that large lava flows – similar to the ones in Iceland – may have interacted with near-surface water to generate hydrothermal environments.

"One of the astonishing things about the recent Holuhraun eruption is how quickly life populated its lava-induced hydrothermal systems," says Christopher. "Just months after the end of the eruption, hot springs emerging from the lava flow contained algae and other microorganisms that may have been hiding dormant in the sand, just waiting for the right conditions to spring back to life." If similar microbes live on Mars, large volcanic eruptions might hold the key to the episodic flourishing of microbial life on Mars.

COULD THERE BE LIFE ON MARS?

Solange and Christopher's studies have shown that life very quickly emerged in the lava-induced hydrothermal systems, which gives rise to the possibility that there could well be life in similar environments on Mars. The identification of potentially habitable locations on other planets is a fundamentally important issue, and NASA's Mars 2020 mission – currently en route to Mars – will be the first rover capable of collecting astrobiologically relevant samples for return to laboratories on the Earth. This mission is particularly exciting because it will land in Jezero Crater, which includes volcanic units that may have generated hydrothermal systems just like the ones observed in Iceland.

A MARRIAGE OF DISCIPLINES

Solange and Christopher met while working on separate research projects in Hawaii twelve years ago. Now married, they have not only established their own successful careers investigating different scientific problems in environmental microbiology (Solange) and planetary science (Christopher), but have also come together to work on fascinating projects, such as this one in Iceland.

From those individual research projects in Hawaii, to travelling the world and conducting their own novel research, to collaborating together to investigate life in extreme environments, Solange and Christopher remind us just how much there is to explore in our world and how individual strengths and interdisciplinary collaboration reap rewards. The question is, where in the world will your explorations take you?

ABOUT EXTREME ENVIRONMENTS

Extreme environments are inhospitable for life because of their extreme conditions, which can include very high or low temperatures, a lack of access to nutrient and/or energy sources, or high or low pressure. As far as our own planet is concerned, the Arctic and Antarctic regions include some of Earth's most extreme environments due to how cold it is there. There are also parts of our ocean that are so removed from land that they are starved for nutrients, making it difficult for life to exist there.

However, life is incredibly adept at adapting to extreme environments, which is why life exists in some of the harshest environments on Earth such as the Marianas Trench and the Antarctic Dry Valleys, which represent great analogues for Ocean Worlds, and present-day Mars, respectively.

WHICH OTHER EXTREME ENVIRONMENTS HAS SOLANGE TRAVELLED TO?

Solange says that one of the most extreme marine environments she has had a chance to study is the centre of the South Pacific subtropical gyre. "This part of the ocean has the clearest waters on Earth because it is so remote that it receives extremely little inputs from the land via riverine or atmospheric inputs," says Solange. "I sampled this location during the BIOSOPE (Blogeochemistry and Optics SOuth Pacific Experiment) expedition on board the French research vessel l'Atalante, at the very beginning of my PhD. I was very excited because this trip gave me the unique opportunity to visit Chile and Tahiti, but also Easter Island! Being so far from land this environment is extremely oligotrophic, meaning that nutrient concentrations are very low. Nonetheless, we found that phytoplankton, the tiny plants drifting in the ocean, still live there, but growing very slowly."

WHAT OTHER TOPICS IS SOLANGE RESEARCHING?

As an oceanographer, Solange is engaged with many forms of research. One of her focuses is the role of phosphorous within microbial metabolisms and in ocean productivity. Phosphorous is indispensable for life, but most of the surface ocean around the world has very low phosphate concentrations, which is thought to be the preferred source of phosphorus for microbial nutrition. This can limit oceanic carbon fixation and affect the structure of ecosystems, but marine microbial communities have evolved fascinating adaptations to cope with the scarcity of phosphate. Solange explores these adaptations and how they differ depending on the amount and chemical forms of phosphorous in a given marine environment.

WHAT ABOUT CHRISTOPHER?

Christopher is the Principal Investigator of the RAVEN (Rover–Aerial Vehicle Exploration Network) project, which is funded through NASA's Planetary Science and Technology through Analog Research (PSTAR) programme to establish new approaches for exploring Mars. "The new Mars 2020 mission includes the Perseverance rover and a small helicopter named Ingenuity. Ingenuity will demonstrate that it is possible to fly a drone within the thin atmosphere of Mars. However, after completing its technology demonstration, Ingenuity will be retired so that Perseverance can focus on its prime mission, which is to search for evidence of past habitable environments and collect samples to return to Earth in the future," explains Christopher. "Once flight has been demonstrated within a Martian environment, a whole new approach to Mars mission design will be possible."

RAVEN will explore this new frontier by using the Canadian Space Agency's Mars Exploration Science Rover (MESR) in combination with custom-designed drones to develop new technologies and science operational scenarios for using a rover together with a drone. It will also explore the Holuhraun area in Iceland to test new instruments and navigation systems in an environment that is similar to Mars. Ultimately, the project will pave the way for the next generation of robotic spacecraft on Mars.

WHY IS COLLABORATION SO VITAL FOR THE RESEARCH THAT SOLANGE AND CHRISTOPHER CONDUCT?

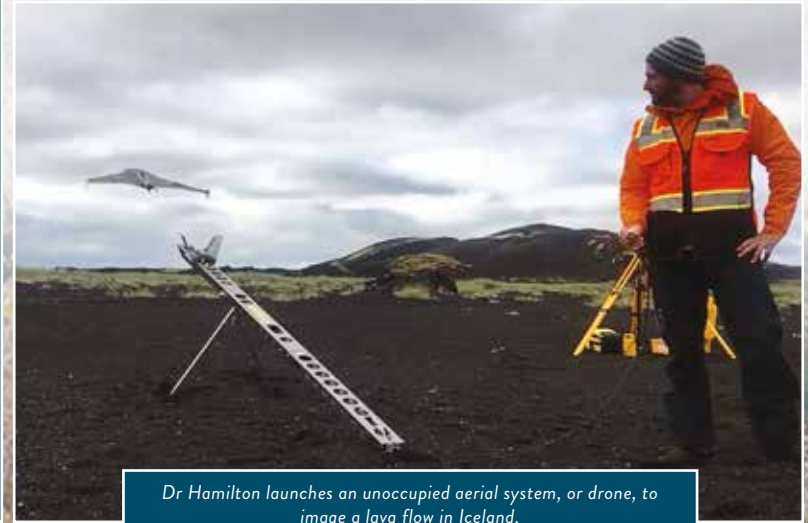
Put simply, collaboration enables a team to combine a broad range of complementary skills, knowledge and expertise. No one person can do it all. Understanding complex ecosystems such as marine and hydrothermal environments requires combining the skills of scientists with various backgrounds in biology, chemistry, geology, physics and computer sciences. Then there is planetary science, which is a complex discipline and no one person can be an expert in every aspect of it. Collaborations like Solange and Christopher's generate exciting new ideas and enable researchers to solve challenges that would otherwise be impossible.

PATHWAY FROM SCHOOL TO OCEANOGRAPHY

Oceanography covers a wide range of topics; it is multidisciplinary. Solange recommends taking biology, chemistry and ecology. "For a career in oceanography, it would be useful to also study biogeochemistry and physics, if possible," says Solange. She also recommends taking a course in statistics which is fundamental for data analyses.

You'll need a degree in a relevant subject such as ocean science, geology, biology, chemistry or environmental science for postgraduate study.

Salaries in this field can vary hugely. Solange recommends the following website for you to find out more: **https://www.marinecareers.net/salaries**



Dr Hamilton launches an unoccupied aerial system, or drone, to image a lava flow in Iceland.

HOW DID DR SOLANGE DUHAMEL BECOME AN OCEANOGRAPHER?

DID YOU ALWAYS WANT TO BE A SCIENTIST?

My dream job as a child was to be a teacher. I always loved science, but I also had various interests in music, art and literature. Overall, I could never settle on a specific topic because I found too many things interesting. I haven't changed and I am lucky that my job allows me to be creative and explore new things!

WHO OR WHAT HAS INSPIRED YOU IN YOUR CAREER?

I grew up in a very modest family and I am a first-generation college student. Science was not a topic of conversation at home. But I have been fortunate to meet inspiring teachers and mentors who passed on their passion for natural sciences to me, and my family has been supportive of my unusual career choice.

WHAT AMBITIONS DO YOU STILL HAVE TO ACHIEVE?

I still have a long list of extreme environments that I would like to study one day. On top of my list is Antarctica.

Dr Duhamel uses a multiparameter water quality sonde to measure environmental conditions within an acidic volcanic lake.

HOW DID DR CHRISTOPHER HAMILTON BECOME A PLANETARY SCIENTIST?

WHAT WERE YOUR INTERESTS AS A CHILD?

I liked LEGO, especially Space LEGO! I built spaceships and explored alien worlds on the floor of our house. Growing up, I also spent a lot of time outside, walking through the woods and climbing rocks. I was always curious to know how the world worked and, even in elementary school, I wanted to be scientist. At the time, I did not understand what that meant, but my passion for exploring and striving to understand how things work has always continued to grow.

WHO OR WHAT HAS INSPIRED YOU IN YOUR CAREER?

My great grandfather, Dr Henry Jermain Creighton, was an extremely talented electrochemist who made a number of major contributions as a scientist, including working on the Manhattan Project; developing artificial polymers at DuPont, like nylon; and inventing a commercial process to convert glucose into sorbitol, which is an important chemical used as sugar substitute and to synthesise ascorbic acid (vitamin C). I never met my great grandfather, but tales of this work were an inspiration.

WHAT AMBITIONS DO YOU STILL HAVE TO ACHIEVE?

I want to continue exploring how the world works and to make tangible steps towards understanding the history of the Solar System. These are small steps toward the longer term goal of helping humanity journey to the stars. Space exploration is not something that is achieved by one person – many people contribute to it as a common goal. I am proud to have a role in this journey and, if I have one ambition, it would be to encourage other people to also find ways to participate in the process of space exploration.

PATHWAY FROM SCHOOL TO PLANETARY SCIENCE

As is often the case with scientific subjects, mathematics is critical. "The more fluent a person can become with mathematics, the easier it will be to develop a career as a scientist," says Christopher. "That said, a successful scientist must also be creative and so finding a unique connection between two or more different fields will help to establish a unique perspective. In my case, I have a background in geology, astronomy, and architecture, and along the way focused on geophysics and computer science."

You'll need a degree in a relevant subject for postgraduate study, such as maths or physics.

Christopher reminds us that salaries in this field can vary depending on experience, location, institution, the number of research projects you work on and the funding you receive.

To find out more, visit: **https://learn.org/directory/category/Physical_Science/Physical_and_Earth_Sciences/Planetary_Sciences_and_Astronomy.html**

SOLANGE AND CHRISTOPHER'S TOP TIPS

1. The secrets to being a successful scientist are creativity and perseverance. Every part of the universe is extraordinary, and every process is connected, so find something that intrigues you and examine it closely – eventually, the connections between it and everything else will begin to emerge.

2. Science will never answer the question of why things are connected, but it can show us *how* things are connected. Do not worry about following in anyone's footsteps. It does not really matter where you begin in your scientific journey because all paths eventually connect to one another.

3. If possible, secure an internship placement in a research group. This will give you a real sense of whether you are taking the right pathway and, if you are, it should help you become even more passionate about your chosen scientific field.

IN THE KNOW: BUILDING A CLIMATE LITERATE SOCIETY

CLIMATE CHANGE IS DESTINED TO BE A MAJOR CHALLENGE FOR SOCIETY, AND TACKLING IT EFFECTIVELY RELIES UPON US KNOWING WHAT WE ARE DEALING WITH. **DR LESLEY-ANN DUPIGNY-GIROUX**, OF THE **UNIVERSITY OF VERMONT**, HAS DEDICATED HER CAREER TO COMMUNICATING ABOUT CLIMATE CHANGE, TO AUDIENCES RANGING FROM POLICYMAKERS TO PRESCHOOL CHILDREN. LESLEY-ANN BELIEVES THAT CREATING A CLIMATE LITERATE POPULATION THROUGH EDUCATION AND INCLUSIVITY IS CRUCIAL FOR THE FUTURE OF SOCIETY

TALK LIKE A CLIMATOLOGIST

CLIMATE – the average conditions of the atmosphere, vegetation, water bodies and soils of an area, including but not limited to temperature and weather patterns

CLIMATE CHANGE – a sustained change in the average conditions of the climate of an area over a long period of time

CLIMATE LITERACY – an understanding of the elements of the climate system, how the climate is observed and modelled, humanity's impacts on the climate, and of the impacts of climate change on human societies

CLIMATE MODELLING – using mathematical or computer-based methods to create models that simulate climate systems and predict trends

LAPSE RATE – the rate at which air temperature falls with increasing altitude

REMOTE SENSING – collecting data from a distance, such as by using satellites, balloons, drones or aircraft

SOCIAL CONSTRUCTIVISM – knowledge that is socially situated, by being connected to a familiar location or experience

SYSTEMS THINKING – recognising the role of interconnectedness and influence between entities

WEATHER – the state of the atmosphere at a particular place and time

Dr Lesley-Ann Dupigny-Giroux has an illustrious career with many titles to her name. As well as researching fields such as climatic natural hazards and remote sensing, not to mention working with key state decision-makers on climate action plans, she also devotes much of her time to building climate literacy. "Being climate literate is more critical than ever before," she says. "If we do not understand weather, climate and climate change as intricate and interconnected systems, then our appreciation of the big picture is lost."

Specifically, Lesley-Ann believes in the importance of understanding humanity's influence on changing the climate. "Once we appreciate this concept fully, it can lead to positive behaviour change," she says.

WHAT IS CLIMATE LITERACY ALL ABOUT?

"Systems thinking lies at the heart of climate literacy," explains Lesley-Ann. She is referring to being able to visualise the climate system as an entity that is constantly being influenced by a huge array of different factors: forests, oceans, cloud cover, ice cover, and, of course, humanity's impact, to name but a few. "Understanding all of this requires learning in a flexible and interdisciplinary way," she says. "Critical thinking, reasoning and attention to detail are all important."

"As a society, I believe we are becoming more climate literate," says Lesley-Ann. "This is demonstrated through the various

DR LESLEY-ANN L. DUPIGNY-GIROUX

Professor, Department of Geography, University of Vermont, USA

FIELD OF RESEARCH

Climatology, Climate Change and Climate Literacy

FUNDERS

National Science Foundation; American Association of University Women; NOAA PACE Postdoctoral Fellowships Program; U.S. Centers for Disease Control; National Climatic Data Center (now the National Centers for Environmental Information); Vermont Agency of Education; American Association for the Advancement of Science (AAAS) Women's International Science Collaboration Program; University of Vermont

adaptation and mitigation action plans being rolled out at local, regional and national levels." The International Panel on Climate Change is generally considered the leading authority on climate modelling and predictions for the future, and Lesley-Ann says that its findings are increasingly being used in university classes and by decision-makers.

DOING IT FOR THE KIDS

Lesley-Ann works with people of all ages, including very young children. "When working with kindergarten kids, I often take the 'edu-tainment' approach," she says. "I use fun activities to introduce scientific concepts. It's also easier to engage them in weather-related issues because they can relate these to their daily lives."

She recounts a memorable outreach event on 'Things that Fly' at a local science museum. "It was fascinating to watch my undergraduate students teach kindergarteners about concepts such as atmospheric turbulence ('why planes go bumpity bump') and albedo ('why do you need sunglasses in a plane') through acting it out with them." She also remembers children's excitement at launching a weather balloon: "Two four-year-olds were yelling, 'Gimme more data', conscientiously noting down every time the balloon transmitted data to the ground," she says. "A 7-year-old present there was able to conclude, 'As the balloon goes up, it gets colder' – in other words, the textbook definition of a lapse rate."

HOW TEACHERS CAN GET ON BOARD

To bring climate literacy into the classroom, Lesley-Ann recommends a 'social constructivist' approach. This refers to using information and situations that students are already familiar with through their everyday lives and building upon these to introduce the relevance and importance of climate science. "I suggest using local examples as far as possible, because it is easier to introduce and explore climate change impacts through observations that are closer to home," she says.

Lesley-Ann also recommends forming partnerships with other schools in different areas, even abroad, so that students can compare experiences of climate change and build their interpersonal skills simultaneously.

OUTREACH AT THE UNIVERSITY OF VERMONT

The University of Vermont has a range of committed outreach programmes. "As a land-grant institution, the university is dedicated to providing outreach to people of the state," explains Lesley-Ann. "This means many people at the university work closely with NGOs and governmental agencies, tackling challenges such as pollution in Lake Champlain or social re-location following Tropical Storm Irene in 2011." Additionally, high-impact practices are prioritised at the university as a cornerstone of undergraduate education. "We strive to help develop students' critical thinking skills via experience," says Lesley-Ann. "This includes internships in Vermont or further afield; opportunities to work in partnership with community organisations; and capstone projects that showcase students' learning during the course of their degree." Lesley-Ann gets directly involved in these high-impact practices. "I am currently teaching a first-year class using the lens of remote sensing and human vulnerabilities to lead students through the transition from high school to university," she says.

LESLEY-ANN SHARES HER CAREER HIGHLIGHTS

DIVERSITY CLIMATE NETWORK

The Diversity Climate Network was a National Science Foundation award that ran from 2009-2013. Interestingly, at that time, we found that potential careers in climate science or geoscience didn't really resonate with high school students. These days, that is no longer the case, since the impacts of our changing climate have become much more obvious and prevalent. The project really highlighted the importance of mentoring at all levels, especially peer-to-peer mentoring. It also taught students valuable networking skills, which are likely to continue to help them in their professional lives today.

The diversity aspect of the project has also become even more pertinent since the project ended. We are at a watershed moment for diversity, equity and inclusion. Increasingly, we are understanding the interdependence of climate literacy, access to knowledge, and social and environmental justice. Renewed interest in the project's Facebook page suggests that these lessons from a decade ago are resonating with today's conversation.

VERMONT STATE CLIMATOLOGIST

This title relates to my work in five main areas: communications, information services, research, education, and monitoring and impact assessment. This means that I provide climate data, along with expert opinions and recommendations, to Vermont citizens and beyond. I also work closely with Vermont State agencies on topics such as groundwater resilience and planning for climate change. I am also called upon to work with regional decision-makers and am often interviewed by the media.

LEAD EDITOR OF 'HISTORICAL CLIMATE VARIABILITY AND IMPACTS IN NORTH AMERICA'

This work was the first of its kind in the US to piece together climate variations over the last 200-300 years in order to set modern-day climate change into a longer-term context. A lot of the research can be gleaned from meticulously combing through historical documents, such as archive books, maps, newspapers and even old diaries. I hope this book will continue to highlight the importance of such interdisciplinary skills to broaden our knowledge about the past, present and future.

PATHWAY FROM SCHOOL TO CLIMATOLOGIST

Lesley-Ann recommends taking subjects such as geography, environmental sciences, mathematics, physics, chemistry and geospatial technologies. She highlights the importance of a broad education to understand the interconnectedness of the world around you.

Visiting the ASOS equipment at the airfield at the Burlington International Airport with my climatology class. © Lesley-Ann Dupigny-Giroux

HOW TO BECOME A CLIMATOLOGIST

- Climatology is a moderately rare subject to study exclusively at the undergraduate level and is traditionally found in geography departments. Atmospheric science, meteorology or geography are all closely related courses. Other subjects such as mathematics, physical sciences, agriculture, public health and computer science can also lead to a career in climatology.
- Lesley-Ann studied geography at university. According to the QS World University Rankings, the best universities for geography are Oxford, LSE (London), Cambridge, the University of California Berkeley, and the University of California Los Angeles.
- According to Salary Expert, the average climatologist salary in the USA is $99k per year.

HOW DID LESLEY-ANN BECOME A CLIMATOLOGIST?

WHAT WERE YOUR INTERESTS AS A CHILD?

I was an avid reader, and the Nancy Drew mysteries were a firm favourite. Perhaps this provided the seed that germinated into my lifelong interest in looking for patterns and exploring the 'why' behind places and events – in other words, the study of geography! My other passion is photography, and upon reflection I believe this fed my love for using satellite and aerial images to figure out processes and patterns at the landscape scale.

WHO INSPIRED YOUR CAREER?

My love of all things geography came from my Dad. He was a master at finding the quickest routes between places, decades before Google Maps was around! This made a lasting impression on my search of interconnections across the landscape. Professionally, I have been most inspired by my two mentors. Dr Warren M. Washington is a world renowned climate scientist, who was the inspiration behind the Diversity Climate Network, which helps open doors for students from diverse backgrounds. Mr Harry Van Loon, who is famous for his work on the North Atlantic Oscillation, taught me the art and science of communicating across multiple languages, platforms and perspectives.

HAVE YOU EVER HAD ANY EUREKA MOMENTS?

More often it's a gradual process of realisation. For instance, having supportive and empathetic mentors who I can look up to has been invaluable for my personal growth. You always need someone in your corner to support you, while also challenging you to be the best you can be. Similarly, working with a multitude of teachers and students across many grade levels and school environments has made me a better teacher, principally through fine-tuning my ability to co-create information rather than merely impart it.

WHAT HAS BEEN THE ROLE OF COLLABORATION IN YOUR CAREER?

Because my work concerns many different disciplines, I have always endeavoured to push the boundaries of my research. This had led me to collaborate with educators to advance climate literacy; universities across the US on diversity in climate science; forestry professionals to investigate climate change's impact on Vermont's iconic sugar maples; and the National Weather Service to address urban flooding. Most importantly, I have worked with many cohorts of students on topics ranging from remote sensing of ice storm damage, to roads and conservation.

HOW DO YOU OVERCOME OBSTACLES?

To deal with challenges such as negative reviews, for instance, I find it is helpful to walk away, divert my energy elsewhere for a while and then return with a fresh perspective. Then, I can work through the critiques and use them to grow and improve as a researcher, scientist or teacher.

WHAT KEEPS YOU MOTIVATED?

My greatest motivation comes from interactions with students and lifelong learners. I find the greatest reward is seeing that 'lightbulb moment', when a student grasps a concept and is able to explain it excitedly to another student – or even to future colleagues, years later.

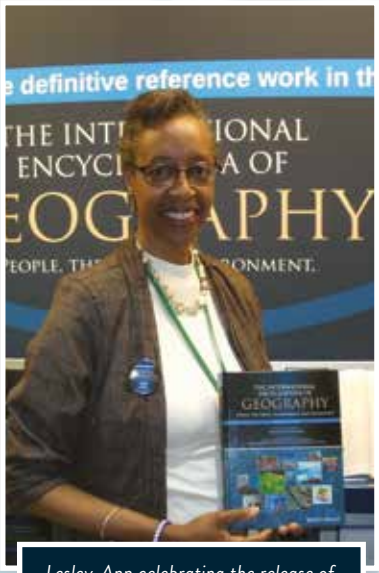
LESLEY-ANN'S TOP TIPS FOR STUDENTS

01 – Always think outside the box. Don't be afraid to try something that has never been attempted before. That's how we find solutions to age-old problems.

02 – Seek out a good mentor, someone who can support you and with whom you can have honest and life-changing conversations.

03 – Never stop asking 'why', and always look for patterns. That's how you can discover the core of an issue, or the hidden pieces of the puzzle that nobody else has noticed.

Lesley-Ann at the Storm Peak Laboratory, Steamboat Springs, Colorado in July 2009, where, as a successful senior women scientist, she was invited to discuss her career and life path at the Atmospheric Science Collaborations and Enriching NeTworks (ASCENT) workshop.



Lesley-Ann celebrating the release of the chapter she was invited to write on Climate Literacy in the International Encyclopedia of Geography in April 2017. © Lesley-Ann Dupigny-Giroux

HOW DOES CLIMATE CHANGE AFFECT WATER QUALITY?

CLEAN WATER IS OUR MOST IMPORTANT NATURAL RESOURCE. WE NEED A RELIABLE SUPPLY OF DRINKING WATER TO LIVE. WE ALSO NEED WATER FOR INDUSTRY, AGRICULTURE AND EVEN RECREATION. HOWEVER, MANY OF THESE USES PUT AN INCREDIBLE AMOUNT OF PRESSURE ON WATER RESOURCES – A PROBLEM LIKELY TO GET WORSE DUE TO CLIMATE CHANGE. **PROFESSOR LI LI**, FROM **PENNSYLVANIA STATE UNIVERSITY** IN THE US, DEVELOPS COMPUTER MODELS TO UNDERSTAND AND PREDICT HOW WATER QUALITY IS INFLUENCED BY CLIMATE CHANGE AND MAN-MADE CHANGES TO THE ENVIRONMENT

TALK LIKE AN ENVIRONMENTAL ENGINEER

BIOGEOCHEMISTRY – The study of the geochemical and biological processes in the natural environment including rivers, lakes and soils

HYDROLOGY – the study of the distribution, movement and management of water, including water cycle and water resources

MICROBIOLOGY – the study of microorganisms, including viruses, bacteria and fungi

ECOLOGY – a branch of biology concerning how plants and animals interact with the environment

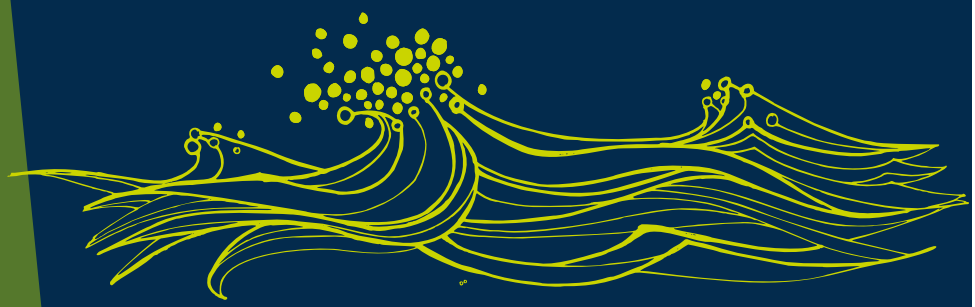
GEOLOGY – the study of rocks and processes by which they are formed

WATERSHED – an area of land through which water from rain, snow or ice drains into, such as a river or lake. It can be a vast area, like the land area that drains into oceans, or very small, like the land area that drains into a very small stream

WATER POLLUTION – when dangerous substances like toxic chemicals or microorganisms contaminate the water and affect the water quality

ORGANIC MATTER – material coming from living things (e.g. animals or plants) or their waste products

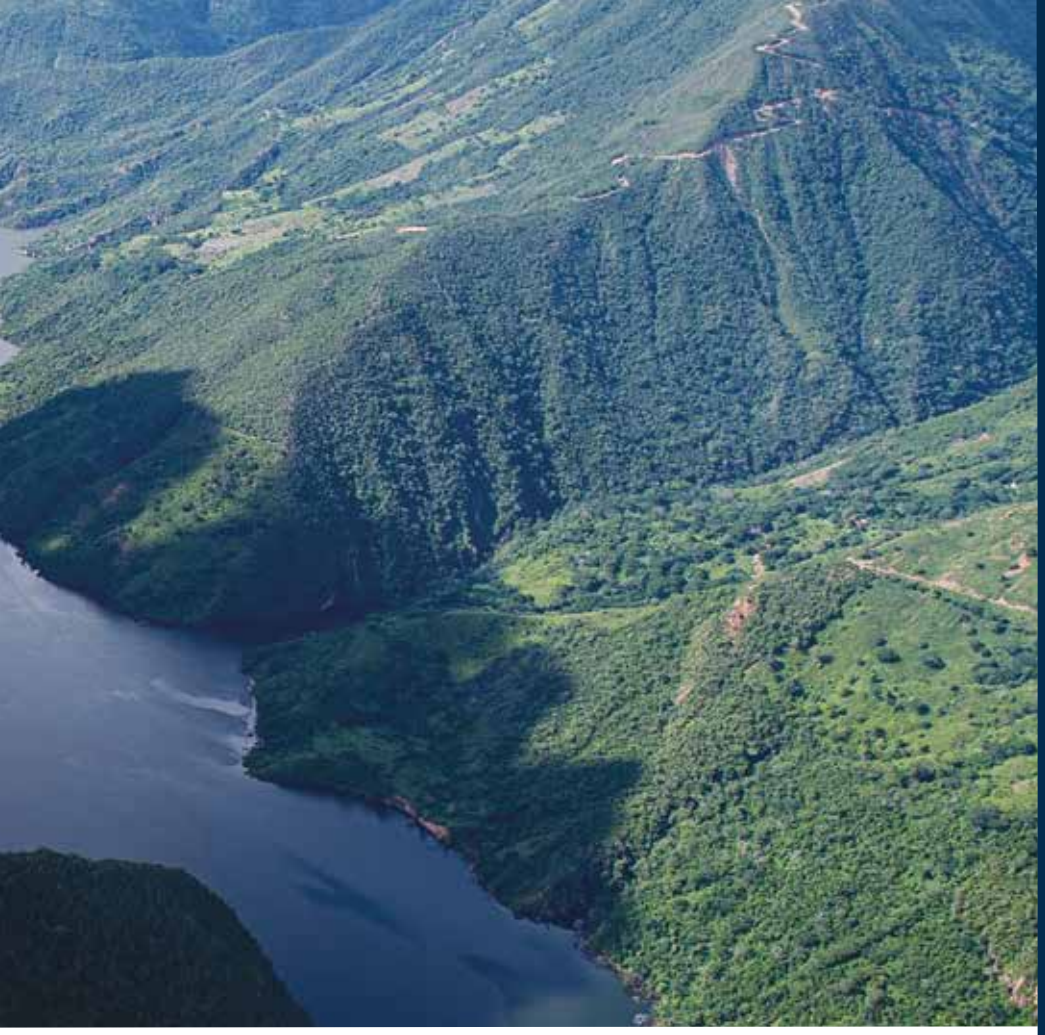
WASTEWATER – any water contaminated after human use, including domestic, industrial or agricultural uses. It may contain chemical, physical and biological pollutants



In developed countries, where water is available through the simple turn of a tap, it is easy to take the resource for granted. However, for many people around the world, finding a source of clean water is a serious problem and may involve hours of travel. Wherever we are in the world, the reality is that the freshwater systems of our planet are under threat from inappropriate land uses, water pollution and climate change.

Addressing these problems and their potential consequences is a huge and urgent challenge. Prof Li Li and her team, the Li Reactive Water Group, based at the Pennsylvania State University in the US, want to tackle these issues before it is too late. They want to understand how climate change and modifications created by humans, such as converting forest area to agriculture, can influence water quality. Li explains, "Such understanding will ultimately help us develop theories and models that can be used to forecast water quality in streams, rivers, lakes, and groundwater, in a way similar to weather forecasting. This is important for risk assessment, mitigation and adaption strategies as these changes continue to threaten water security."

Li recognises that the only way to move forward is by collaborating with other research groups around the world. There have been movements in the science community to work together across traditional disciplines such as physics, chemistry, geology and ecology. This is important because



@LiReactiveWater
https://lireactivewater.wixsite.com/group

PROFESSOR LI LI

Professor of Environmental Engineering
Li Reactive Water Group
Department of Civil and Environmental Engineering
Pennsylvania State University
USA

FIELD OF RESEARCH

Environmental Engineering and Water Resources

RESEARCH PROJECT

The development of computer models to understand how climate change and modifications to the environment created by humans – such as cutting forest for use in agriculture – can affect water quality.

FUNDERS

US National Science Foundation,
US Department of Energy

in natural systems such as watersheds and lakes, all processes influence each other, regardless of artificial disciplinary boundaries. The novelty of this approach is that it brings together scientists from different fields to understand how different things work together and to find novel, 'outside of the box' solutions. The team has established strong links with hydrologists, microbiologists, ecologists, geologists and biogeochemists, to name just a few. These scientists collect data that reflect how water flows, how plants use water, and how microbes work in soil and produce chemicals.

Ultimately, the cross-disciplinary teams can use the data and create computer models that can be used to predict how climate and human-made changes impact water quality in a certain area over time – a forecast of water quality.

There is no doubt that climate change has already affected and will continue to affect our water resources. What is worse is that water pollution, due to excess use of fertiliser in farms, wastewater from factories, or sediments from trees cut for construction, is adding toxic chemicals into rivers and streams that eventually flow into oceans.

One type of chemical that is of particular interest to Li is called dissolved organic carbon (DOC), which comes from the breakdown of living things, such as leaves and roots. It can drag dangerous contaminants into the water, as well as making water treatment a challenging process. Analysing levels of DOC is a good way to estimate how much CO_2 can be released from organic matter, which is eventually emitted back to the atmosphere. For Li, DOC, "has an important role in determining the CO_2 level in the atmosphere, which has significant links to climate warming." However, it is important to note that changes in DOC are not necessarily caused by climate change. Many factors can influence this parameter, including acid rain and changes of land use, such as converting forests to cropland. In addition, soils recovering from acid rain are likely to release more DOC into the water, which has been observed in many parts of the world.

Initial results from Li's team already show how DOC - and inevitably the amount of CO_2 - can change during wet and cold versus dry and hot conditions. It turns out that areas surrounding rivers, lakes and reservoirs – known as the watershed – can hold the DOC from organic matter in the dry summer but release it quickly in the wet winter and spring. This release is not entirely surprising, as rain and snowmelt washes these chemicals down into the water. What is interesting, however, is the fact that Li and her team can now predict, with some levels of uncertainty, what may happen in extreme situations, like heavy rain and flooding, which are likely to accentuate the release of organic matter.

Li explains, "The models we built can potentially be used by companies, governments and environmental organisations to understand how water quality change under different scenarios such as flooding or droughts. This information can then be used to assess risks and decide strategies to mitigate or solve the problems."

If you have a desire to investigate and solve environmental problems, then this could be a career for you. According to environmentalscience.org, there is a growing demand for professionals driven by increasing concerns about climate change and water quality. As a tester, you may want to visit Li's lab for a fun day of activities testing the pH of different liquids like orange juices, vinegar, Coke, or even tap water. Or you may even apply for one of their summer courses learning computer modelling and data analysis.

ABOUT ENVIRONMENTAL ENGINEERING

Environmental engineering is an exciting field to study. Professionals in this field use principles of engineering, as well as soil science, chemistry and biology to find solutions to solve environmental problems. They can work in varied settings such as education, public health, pollution control or recycling. They can also work in government and make environmental related laws and policies, or consulting companies to help solve water resources and water quality related problems.

WHAT IS SO REWARDING AND CHALLENGING ABOUT ENVIRONMENTAL ENGINEERING?

A career in environmental engineering is undoubtedly challenging as there are many environmental issues that need a solution. Problems like climate change and water pollution are hard to solve because they are not localised problems, they are worldwide. Their resolutions require understanding human behaviour and societal issues. As an environmental engineer, collaboration and finding common ground is challenging, but it is the key to solving these issues. The reward is huge – you can help get clean water to millions of people who are in need or help make laws and regulations that combat climate change.

HOW CAN ENVIRONMENTAL ENGINEERING ADDRESS CLIMATE CHANGE?

Climate change is not like any problem we have faced before. It is on a global scale and requires cooperation of people from different countries. This problem can only be solved with innovative new ideas and technologies. Environmental engineers cannot solve the problem by themselves - they will need to work with ecologists, geologists and hydrologists to understand processes in natural systems. They will also need to work with social scientists to understand how human behaviours change processes in built environments

WHAT ARE THE ESSENTIAL SKILLS REQUIRED FOR A CAREER IN ENVIRONMENTAL ENGINEERING?

Above all, environmental engineers are problem solvers. These professionals must be able to identify and anticipate problems before they are able to address these issues. Good interpersonal skills are also a must, as environmental engineers often work in large teams, from scientists, engineers, to social scientists and economists. Finally, complex jobs may require a certain degree of imagination, to foresee how the proposed solution is going to work in real life.

HOW TO BECOME AN ENVIRONMENTAL ENGINEER

- A degree in environmental engineering will give you a good range of skills to offer your employer and strong career prospects. You can also aspire to become an environmental engineer if you have a degree in a related field, such as hydrology, ecology, geology or chemistry.
- Going for a professional engineering licence will allow you to aim for higher roles with more responsibility. After licensing, environmental engineers can register with the American Academy of Environmental Engineers and Scientists: **https://www.aaees.org/becomeboardcertified.**
- Options for careers are incredibly varied and can come from different sectors, including agriculture and forestry, water management, environmental policy and public health. You may find opportunities in engineering companies or as a consultant. Some positions may even offer the chance to travel to participate in different projects around the world.
- According to the US Bureau of Labour Statistics, (2020), entry-level environmental engineers can earn up to $88,000 annually.

PATHWAY FROM SCHOOL TO ENVIRONMENTAL ENGINEERING

The best subjects to study to become an environmental engineer are maths, physics, biology and chemistry. Many universities offer a degree in environmental engineering, including Princeton University, MIT and Stanford University. In most cases, you can choose from a wide range of specialisms, allowing you to focus on a particular area and hone your skills for the job that you want. Typically, these specialisms include air quality, waste management and water resources, among others.

Li recommends taking extra courses in coding, computer modelling and data analysis to obtain critical skills and tools to help you in different situations. You may also wish to study further for a master's or a doctorate, but for many roles, this is not essential.

Often, employers value practical experience. There are engineering courses which provide job experience which may be worth considering. For further information, environmentalscience.org is an excellent place to start: **http://www.environmentalscience.org/career/environmental-engineer**

LI'S TOP TIPS FOR STUDENTS

01 - Follow your heart and do what excites you.

02 - Don't let others dictate your future. Don't conform to others' expectations.

03 - Challenge yourself! It's the only way to reach your dreams.

HOW DID LI BECOME AN ENVIRONMENTAL ENGINEER?

WHAT WERE YOUR INTERESTS AS A CHILD?

I loved reading, was good at writing short stories and I aspired to be a writer. I was also interested in the natural world – I was fascinated with lots of different things, such as the sky, trees and sand.

WHO OR WHAT HAS INSPIRED YOU IN YOUR CAREER?

Things changed in my teenage years in high school. In China, teenagers decide in high school whether they want to go for science and engineering, or social studies and humanities. I could not decide, because I was interested in a lot of things and was also good at all these subjects.

One day, I overheard my mom asking for her friend's opinion about which direction I should go in. I overheard them saying that girls are not good at science and engineering and that I should choose social studies or humanities. I was a defiant teenager, and I decided to do the opposite, so I picked science and engineering! Looking back, I realise that I have often done things that are the opposite of what others expect me to do.

WHAT HAVE BEEN YOUR PROUDEST CAREER ACHIEVEMENTS SO FAR?

I am proud that I stayed in academia and still managed to have children. Being a professor and scientist is demanding. Juggling between work and family life is challenging, as both demand time and you only have 24 hours a day! There were multiple occasions when I almost slipped out of this career. For example, when I first had a baby and when I had a difficult time landing a faculty job. I had a lot of support my mentors and collaborators. They helped me look beyond the foggy uncertainties and get through challenging times. I hope my struggles and position help girls who are still deciding about their career see the message, "you can do it too".

My proudest career achievement is that I became a university professor. This position gives me the opportunity to teach and inspire the younger generation and help them realise the severity of many environmental problems. Even if they don't become environmental scientists or engineers, they can still learn how to become responsible citizens that minimise waste input and live sustainable lives - for example, by buying houses powered by solar power and driving cars that do not add a lot of carbon to the atmosphere.

I am also proud that I get to work with graduate students who do environmental-related research. These students progress and become professionals after they finish graduate schools. It is very rewarding to see them grow.

WHAT ATTRIBUTES HAVE MADE YOU A SUCCESSFUL ENGINEER?

I tend to think of my groups' work leaning more toward science instead of engineering. Our goal is to create knowledge and understanding of processes and mechanisms that lead to water quality change, and this knowledge then feeds into the engineer's work in solving these problems.

Diligence, persistence, intellectual curiosity (wanting to know answers and solving puzzles), and aspiration to excel are some of the key traits that make a successful scientist. But everyone is different and has their strengths, so there is not just one formula.

UNDERSTANDING HOW AIR POLLUTION SPREADS

DR APRIL HISCOX, BASED AT THE **UNIVERSITY OF SOUTH CAROLINA**, USA, IS ONE OF THE PRINCIPAL INVESTIGATORS OF THE **SAVANT** PROJECT, WHICH LOOKS AT HOW AIR MOVES AT NIGHT NEAR THE EARTH'S SURFACE. THE FINDINGS WILL PROVIDE INSIGHTS INTO HOW AIR POLLUTION SPREADS, AND HELP TO ENHANCE IMPROVE AGRICULTURAL OPERATIONS

TALK LIKE A GEOGRAPHER

STABLE BOUNDARY LAYER – a cool layer of air adjacent to a cold surface on the Earth, where the temperature within that layer increases with height above the ground

AEROSOL DISPERSION – the process by which particles are spread out while they remain airborne

INTERNAL GRAVITY WAVES – gravity waves that occur in the interior of a fluid rather than its surface

KATABATIC DOWNSLOPE WIND – a wind that carries high-density air from a higher elevation down a slope under the force of gravity

MESOSCALE – an intermediate sized scale between those of weather systems and of microscales, on which storms and other phenomena occur

MICROSCALE – a scale on which short-lived atmospheric phenomena smaller than the mesoscale occur

TURBULENCE – fluid motion characterised by chaotic changes in pressure and flow velocity

CONVERGENCE – a location near the surface where airflows meet, characteristically marked by upwelling

Above the surface on the Earth, there are layers upon layers of air which have varying temperatures and move in different ways, depending on what is happening in the particular atmosphere these layers are located within. Stable boundary layers – which are cool layers of air adjacent to a cold surface of the Earth – are one example of these layers but are notoriously difficult to understand and observe for a range of reasons.

For one thing, they are most frequent at night, so scientists are forced to stay up late in order to observe them! Secondly, they are very near to the ground, too close for typical measurements to capture with typical measurements occurring even just 10 metres from the surface. Finally, they are spatially variable, so observations have to be performed over distances, as opposed to a single measurement.

Dr April Hiscox, based at the University of South Carolina, is a geographer and one of the principal investigators of a project that is using novel methods to overcome some of the difficulties associated with understanding and observing stable boundary layers. Known as SAVANT (Stable Atmospheric Variability ANd Transport), the project will help scientists understand how air moves at night near the Earth's surface. The findings will provide insights into how air pollution spreads and will help farmers know when it is best to apply pesticides or to deploy frost mitigation strategies.

WHAT IS MEANT BY 'STABLE'?

In atmospheric terms, 'stable' means the suppression of vertical motion. "Stable does

DR APRIL HISCOX

Department of Geography, College of Arts and Sciences, University of South Carolina, Columbia, USA.

FIELD OF RESEARCH

Geography

RESEARCH PROJECT

April is the lead Principal Investigator of a project that seeks to improve understanding and observation of stable boundary layers. The findings will help determine how aerosols are dispersed, which could benefit farmers and improve crop yields.

FUNDERS

National Science Foundation, US Forest Service, US Department of Agriculture

This material is based upon work supported by the National Science Foundation under Grant No: AGS-1733746, AGS-1733877, and AGS-1844426. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

not mean no motion – in fact, the suppression of vertical motion can often enhance or complicate horizontal motion. The easiest way to define a stable layer is to say it is when there is an inversion of the normal temperature profile," explains April. "So, instead of getting cooler, as you move away from the surface, air gets warmer. It gets cooler because the land gets cooler and cools the atmosphere just above it. By just above, I mean immediately above, like less than a centimetre of air."

To understand the whole process at work, it is necessary to be very close to the ground to measure the starting conditions. Importantly, to gain a full understanding, it is vital that researchers measure both time and space, that is, horizontal and vertical aspects of a layer, on a small scale.

IN WHAT WAYS IS SAVANT UNIQUE?

Put simply, SAVANT is unique because of the tools and methods that the team is using. The difficulties in understanding and observing stable boundary layers mean they are often overlooked in atmospheric models. April's work is addressing this through the use of LIDAR (light detection and ranging) systems. "Scanning LIDARs are relatively rare instruments and our team combined three in the project for one of the first times," says April. "This made our measurements unique, but the experience itself was unique for me too; it was my first time as lead Principal Investigator and it was both fun and exciting!"

The group involved in SAVANT contained an equal number of men and women which is also a novel aspect, especially when you consider that April has often been the only woman involved in other projects. There was also a mix of international students which ensured that people from different cultures came together to achieve a common goal.

HAVE THERE BEEN ANY EXCITING FINDINGS?

Yes! The team's measurements over various surfaces showed that removing crops from the ground has a much larger implication on the stable boundary layer than the team anticipated. There are still lots of data to be analysed, but it appears that there are major differences in how turbulence works before and after crops are harvested. This finding has potentially beneficial outcomes for farmers, as they can determine how aerosols, such as sprays, pesticides and herbicides in crops or forested environments are dispersed. Ultimately, this will help farmers avoid the aerosols drifting off course, which can be economically costly and harmful to surrounding vegetation.

WHAT ARE THE NEXT STEPS FOR THE RESEARCH?

There is still more work to be done and questions to explore, but the SAVANT project has shown it is possible to improve understanding of stable boundary layers and how they can affect the dispersal of aerosols. One thing that April and the team are keen to do is to provide the wider community with access to the instruments they used in the project. This will help to ensure that people working in forestry, agriculture and other levels of the atmosphere can benefit too.

ABOUT GEOGRAPHY

Geography is the study of the physical features of our planet, its atmosphere and inhabitants, and all the complexities these bring. Over the past century or so, human activity has arguably increased the importance of geography, as scientists work to understand the precise ways in which human activity impacts Earth and the surrounding atmosphere. Indeed, without geographers it would be very difficult (if not impossible) to quantify the impacts of global warming and the resultant climate change.

However, geography is an extremely broad subject which offers a huge range of opportunities. April is a geographer, but she also considers herself to be an atmospheric scientist. When we couple that with the fact that two of her three degrees are in engineering, we can see how the sciences can be a glorious melding of separate but related concerns. As such, there is no set pathway to geography, and no pre-defined focus for a geographer.

WHAT DOES APRIL FIND CHALLENGING AND REWARDING ABOUT GEOGRAPHY?

Speaking as an atmospheric scientist, April says the most challenging aspect is having to explain to people that she does not study the weather that we see on TV every day! While she teaches the principles behind forecasting, it is not what she studies. "There are many rewarding aspects of my field of research," says April. "However, the most rewarding is knowing that even if my work cannot tell you whether to take an umbrella out tomorrow, it can help protect our food supply and natural environment."

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

As we alluded to in the introduction, geographers are providing fascinating and extremely important insight into the negative impacts of human activity on our planet. However, it is worth noting that the most pressing issue will differ depending on the type of geographer you are. For April, it is climate change; from the physical changes to the world to its impact on human activity, it is fair to say that there is virtually no aspect of our lives and no topic that will not be affected by our changing climate.

WHERE WILL APRIL'S RESEARCH LEAD TO IN THE FUTURE?

April says this is a really hard question to answer, not least because SAVANT has been her dream project ever since she was a graduate student. "As the results from SAVANT start to come in, I could take my research path in many directions," explains April. "More stable boundary layer explorations are definitely there – we had many questions going into SAVANT and while we will answer some, more came up. My long-term hope is that we can reliably predict exactly when stable conditions will occur and where aerosols released into stable layers will end up."

As a geographer, what questions would you be asking? What would your dream project be?

HOW TO BECOME A GEOGRAPHER

- The American Geographical Society is an excellent starting point for those interested in pursuing a career in the field: **https://americangeo.org/**
- The American Association of Geographers contains a wealth of information on a career in geography. We encourage you to read through the site to see the opportunities out there: **http://www.aag.org/**
- The average salary for a geographer is $82,000, although this is dependent on an individual's level of experience and whether they are working in the private or public sector.

Graduate student, Erika Chin, repairs fibre optic temperature sensing cable during a late-night measurement campaign. (Credit: April Hiscox)

HOW DID APRIL BECOME A GEOGRAPHER?

WHAT WERE YOUR INTERESTS AS A CHILD?

I was an avid reader and explorer. I loved being outside and, to this day, I love asking questions. My favourite toys were an electrical set and the very early LEGO Technic sets that had a little motor. I also love(d) to travel and see new sights – I wanted to see the whole world! My father was a science teacher, so I had an exposure to it from an early age. At the same time, I loved to create and make things; I am still a keen knitter and quilter.

WHO OR WHAT HAS INSPIRED YOU IN YOUR CAREER?

I've been fortunate to have many people inspire my career. My career path was a bit meandering as it took a while to find exactly which problems I wanted to solve. But I always knew that I wanted to teach in some capacity and I have my parents to thank for that. They have always been inspiring people who love what they do and were role models as educators.

There were also several teachers in high school who encouraged me to explore different options for my major beyond those typically presented to women. Similarly, I was fortunate to have some professors in college who encouraged me to go to graduate school and aim high in doing so. My MS advisor, Tim Kane at Penn State, first introduced me to LiDAR and its use in the atmosphere and, 20 years later, I am still fascinated by shooting a laser at the air! My PhD advisor, Dave Miller, inspired me to look closer to the ground, and every woman I met who has been successful in this field served as inspiration that it was possible to pursue a career in this field. One in particular comes to mind – Britt Holmen, who is currently at the University of Vermont. She was just going through the tenure process when she served on my PhD committee and I valued her candour and honesty about the experience.

WHAT ARE YOUR PROUDEST CAREER ACHIEVEMENTS?

To date, SAVANT is my proudest achievement. The experience has been wonderful – nothing quite beats the feeling of knowing that things have worked. After years of funding requests, development and planning, to know your ideas have worked is incredible. Being out late at night, making observations and having that 'We did it!' feeling means all the stress beforehand is worth it and you have a real sense of validation. Seeing the students who took part in the project being energised, and seeing their interest sparked is also something I am proud of that.

DO YOU HAVE ANY AMBITIONS YOU HAVE NOT YET ACHIEVED?

Yes! On the professional front, I would like to become a full professor someday. However, as I move further into my career, my biggest ambition is to address issues around diversity in STEM and form a more tangible network for women in my local community.

PATHWAY FROM SCHOOL TO GEOGRAPHY

April is a passionate advocate for following your own path, or at least being aware that there is no set way into science and/or geography. "There's a lot more to the world than what we might be taught in the curriculum," says April. "School provides the foundation, but there are so many different pathways you can take and so many different connections between people and science to be made. That's what makes it all so exciting!"

Having said this, April recommends studying maths and any science subjects – developing analytical reasoning skills will stand you in good stead for the future. She also recommends classes in basic computer programming or digital literacy. "Geography is a discipline grounded in space. That is the reason we are typically associated with maps. But we live in a digital world with increasing access to spatial data," explains April. "The future of geography is going to be in aggregating and analysing much of that data, so understanding computers is essential."

You'll need a degree in a relevant subject for postgraduate study and it is worth noting that geographers need a master's degree for most positions. Students usually choose to concentrate their courses in physical, human, or regional geography.

https://www.careerexplorer.com/careers/geographer/how-to-become/

APRIL'S TOP TIPS

1. Never be afraid to ask questions. If you do not know something, or want to learn more about a subject, then ask! Your tutors and teachers are there to tutor and teach – asking questions is a major part of that, because it shows them what you don't know and how they can help to fill in those knowledge gaps.
2. Don't take no for an answer. A career in science will always contain difficult moments and times when things feel too hard. But if you persevere and believe in yourself, it doesn't matter what happens or what anybody says – you can do it.
3. Follow your passion. Being a researcher means being you. It is your unique views and curiosities that will lead to new discoveries, so knowing what you love is the best place to start.

A tracer plume at night. (Credit: April Hiscox)

DETECTING TOXIC SUBSTANCES FOR A GREENER AND HEALTHIER WORLD

DR WENPING YIN, BASED AT **MONASH UNIVERSITY** IN AUSTRALIA, FORMS PART OF A TEAM WORKING AT THE **ARC CENTRE OF EXCELLENCE IN EXCITON SCIENCE**. HER WORK IS FOCUSED ON PHOTOLUMINESCENT CHEMICAL SENSORS WHICH CAN DETECT TOXIC SUBSTANCES. THE FINDINGS WILL MAKE THE WORLD A SAFER PLACE

TALK LIKE A MATERIALS SCIENTIST

CHEMICAL SENSORS – measurement devices that convert a chemical or physical property of a specific analyte into a measurable signal.

ANALYTE – the scientific term for a chemical substance being observed.

FLUORESCENT MATERIALS – materials that emit colourful light when the light or current is given.

QUANTUM DOTS – man-made nanoscale crystals that can make much brighter emitting colour than their larger scale equivalents.

PEROVSKITE NANOCRYSTALS – a class of semiconductor nanocrystals, which exhibit unique characteristics that separate them from traditional quantum dots.

BROMOMETHANE – a colourless, non-flammable gas with no distinct smell. It is the most effective soil fumigant for killing plant pests.

IODOMETHANE – another member of the class of the fumigant. A less toxic replacement after bromomethane.

Toxic substances are those that can be poisonous or otherwise detrimental to the health of human beings, crops and the environment. Some toxic substances are naturally occurring, such as snake venom and caffeine, but whether or not they are harmful is dependent on the levels an individual is exposed to. Often, this requires common sense and being careful, such as when using bleach to clean surfaces, or filling a car with petrol – provided a person acts in a safe manner, no harm will come to them.

However, there are other toxic substances which are used for industrial or agricultural purposes, such as controlling pests in buildings, soils and wood. In these situations, toxic substances are administered in sprays or as fumigants, but only a very small amount of exposure to these substances can cause significant harm. Unfortunately, pesticides such as bromomethane and iodomethane are used around the world, so even if they are administered in small amounts in each location, the total amount administered can be harmful to the ozone layer. Then there is the fact that the amount of toxic substance administered often relies on the experience of the farmer, which is not infallible.

DR WENPING YIN

ARC Centre of Excellence in Exciton Science and Monash University, Melbourne, Australia

FIELD OF RESEARCH

Materials Science and Engineering

RESEARCH PROJECT

Wenping is working to harness fluorescent materials as a means of detecting harmful levels of toxic substances. The findings will have positive impacts for agriculture, but could also benefit defence, biological and other fields.

FUNDER

Australian Research Council

With problems such as these in mind, Dr Wenping Yin is working on a project that harnesses fluorescent materials as a means of detecting harmful levels of toxic substances. Based at the ARC Centre of Excellence in Exciton Science and Monash University in Australia, Wenping is using the knowledge, skills and experience she gained during her doctorate to drive positive change for people, crops and the environment.

WHAT DID WENPING ADDRESS IN HER PHD RESEARCH?

One of the branches of Wenping's doctorate was focused on understanding the limitations of optoelectronic devices which, put simply, are devices that use light in some way such as LEDs, lightbulbs and fibre optic cables. "In any kind of optoelectronic device, our first concern is always to improve the efficiency of the conversion between light and energy, especially when emerging materials like perovskite are just getting off the ground," explains Wenping. "However, as the fundamental technology evolves, the real limiting factor behind it will gradually shift to how to further understand and optimise the physical/chemical processes therein."

These physical/chemical processes generally occur so fast that ordinary electronic detectors are insufficient. Wenping therefore used ultrafast spectroscopy to observe the processes on time scales as short as trillionths of a second. The research that Wenping did during her PhD gave her a deeper understanding of fluorescent materials, which feeds into her current project. Indeed, the work she did during her PhD laid a great foundation for the transition to and development of her current project.

WHAT DOES WENPING'S CURRENT PROJECT INVOLVE?

Chemically detecting harmful levels of toxic substances relies on several processes, such as physical adsorption, chemical response and signal reporting. Of course, given the complexity of what is involved, these practices require significant and complex research, so Wenping and her team are working to reduce or eliminate the steps involved as much as possible. They achieve this by using their skills to design ingenious tools that can facilitate higher sensitivity, faster response and lower cost (particularly important when considering future industrial production). There is also the need to design tools that only react to the target toxic substances. This ensures that the sensors are fit for the environment in which they are being operated.

HAS THE TEAM HAD ANY SUCCESSES SO FAR?

Yes! Wenping and the team have already developed a sensor system that can be used to detect fumigants. "This technology comprehensively surpasses any portable product available on the market in terms of detection speed, sensitivity and selectivity," explains Wenping. "We therefore have reason to believe that this system holds great potential for mass industrial production." The team has filed a patent and is in conversation with the relevant governmental departments in Australia, with a view to rolling it out across the agricultural sector. If this can be achieved, it is entirely possible that there will be other applications in the future, such as defence and biological (e.g. heavy metal).

WHAT ARE THE NEXT STEPS FOR THE RESEARCH?

It is fair to say that Wenping is very ambitious, which is essential when trying to drive new science and technology forward. "My colleagues and I are very willing to believe that this fluorescent sensor system will have a wide range of applications and are trying to develop new materials for various substances detection," Wenping says. "The future challenge for this project will be to make the sensor work in a mixed environment of matter, be it gas, solid or liquid. Another important question is how to integrate different sensor materials to respond with different toxic substances, respectively, without affecting the performance of each component."

We wish Wenping and the team the best of luck!

ABOUT MATERIALS SCIENCE AND ENGINEERING

Materials science is an interdisciplinary field that is focused on the properties of matter and how they can be applied to a wide range of areas within science and engineering. It is one of the oldest forms of applied science and engineering – you will no doubt have heard of the Stone Age, Bronze Age and Iron Age, which are all examples of periods of different areas of focus within materials science.

One of the most significant breakthroughs in the field came when the American scientist, Josiah Willard Gibbs, demonstrated that thermodynamic properties related to the atomic structure of a material were also related to its physical properties. Since then, materials scientists have investigated many materials to determine their structures, properties and performance. This, in turn, has led to technological innovations that have changed the world around us.

WHAT DOES WENPING FIND MOST REWARDING ABOUT WORKING IN THE FIELD?

Wenping says that research is itself a lifelong learning journey and her work involves continuously updating her knowledge, which is one of the greatest attractions of her research. "When I realised that my discoveries could not only guide others but could also be turned directly into products benefiting society, that sense of accomplishment was exactly what I imagined in my childhood," explains Wenping. "I believe this is the most fulfilling moment for every researcher."

HOW DOES HER WORK CONTRIBUTE TO A 'GREEN FUTURE'?

The act of testing for toxic substances is a major contribution to a green future. While technological developments continue apace, the Earth's environment and people's physical health is facing challenges from the harmful chemicals we use in daily activities. While in the past man fought nature, we are now dealing with issues caused by our own actions. The harmful substances that Wenping works to detect are often colourless and odourless, making it extremely difficult for people to know they are there. Her work is helping to contribute to a greener and healthier future.

WHAT DOES WENPING ENJOY AND FIND MOST CHALLENGING ABOUT THEORETICAL AND PRACTICAL PROJECTS?

"There is an old joke in the field: 'Theory is when you know everything but nothing works, practice is when everything works but nobody knows why. When you combine theory and practice, nothing works and nobody knows why!'," says Wenping. "As an interdisciplinary researcher, I can appreciate the meaning behind the joke and there is an element of truth to it."

Ultimately, Wenping believes you need to be careful enough to find problems in practice and smart enough to solve them by theory. So, if you are careful and smart, materials science might just be the field for you.

HOW TO BECOME A MATERIALS SCIENTIST

- AZoM is the leading online publication for the Materials Science community. It works to educate and inform a worldwide audience. Some of the papers on there are quite complex, but it is an invaluable resource for those interested in the field:

  https://www.azom.com/

- There are some videos that provide more information regarding what materials science is. Each video will give recommendations for further exploration:

  https://www.youtube.com/watch?v=JZ9BkoLWdIg&ab_channel=AdvancedMetallicSystemCDT

  https://www.youtube.com/watch?v=_cUEjPtVIIM&ab_channel=MaterialsScience-aChalmersAreaofAdvance

- The salary for a materials scientist in Australia can range from anywhere between AU$60,000 and AU$101,000, depending on the level of experience you have.

PATHWAY FROM SCHOOL TO MATERIALS SCIENCE AND ENGINEERING

Wenping is keen to emphasise that the field of materials science and engineering is quite broad, so there is no set path for those who want to pursue a career in that direction. However, chemistry and physics are especially important and you should take those subjects at school and beyond, if possible. "Courses in analytical chemistry, structural chemistry and quantum physics are important after high school," says Wenping. "Those subjects can help you to understand the equipment and materials you will use in the future."

You'll need a degree in a relevant subject for postgraduate study, such as materials engineering, materials science, applied chemistry and applied physics.

https://nationalcareers.service.gov.uk/job-profiles/materials-engineer

WENPING'S TOP TIPS

1 Interest is the greatest teacher. If you are interested in a topic you are far more likely to learn what you need to succeed. Never do something simply because somebody else tells you to – you must have your own ideas, passions and thoughts. Listen to others but remember to listen to yourself.

2 Focus on what you are doing and never give up easily. My own experience shows that I took many detours on the road to research, but I believe most of this has become beneficial over time. There is no single pathway, but whatever you decide to do, persist!

3 For those interested in teaching like I did earlier in my career, I would say you should not underestimate any student and always encourage them to ask questions, even if those questions fall outside the scope of the lesson. Also, don't be limited to the knowledge found in textbooks – life experiences can be more useful, interesting and inspiring, which often help students get the most out of lessons.

HOW DID WENPING BECOME A PHYSICIST AND MATERIALS SCIENTIST?

WHAT WERE YOUR INTERESTS AS A CHILD?

I was hyperactive when I was a kid, so was a basketball player and sprinter for a couple of years. Although I didn't have a clear scientific dream at the time, I did enjoy all kinds of hands-on work. Almost all the electronic devices in my parent's home were dismantled by me at some point! One of my most memorable moments was when I secretly used a soldering iron and ended up hurting my hand when I was 13. Fortunately, my parents endured all those vandalisms and supported my whimsical creations – which I think is related to the motivation and interest in science I developed later.

WHO OR WHAT HAS INSPIRED YOU IN YOUR CAREER?

Although most of the time I believe that self-motivation is the primary factor of success, there are some people who have inspired and encouraged me in my career. One of them is Professor Villy Sundstrom from Lund University in Sweden, who is a very famous spectroscopy expert. He used the phrase 'Excited by light my entire life' as a summary of his career when he retired, which impressed me a lot. Another moment was when Professor Yi-Bing Cheng – at his own retirement ceremony – chose to appeal to the many scholars present that day not to underestimate any young student because of their nationality. This was deeply inspiring to me and I hope to have a successful and gracious research career without regrets, like they have had.

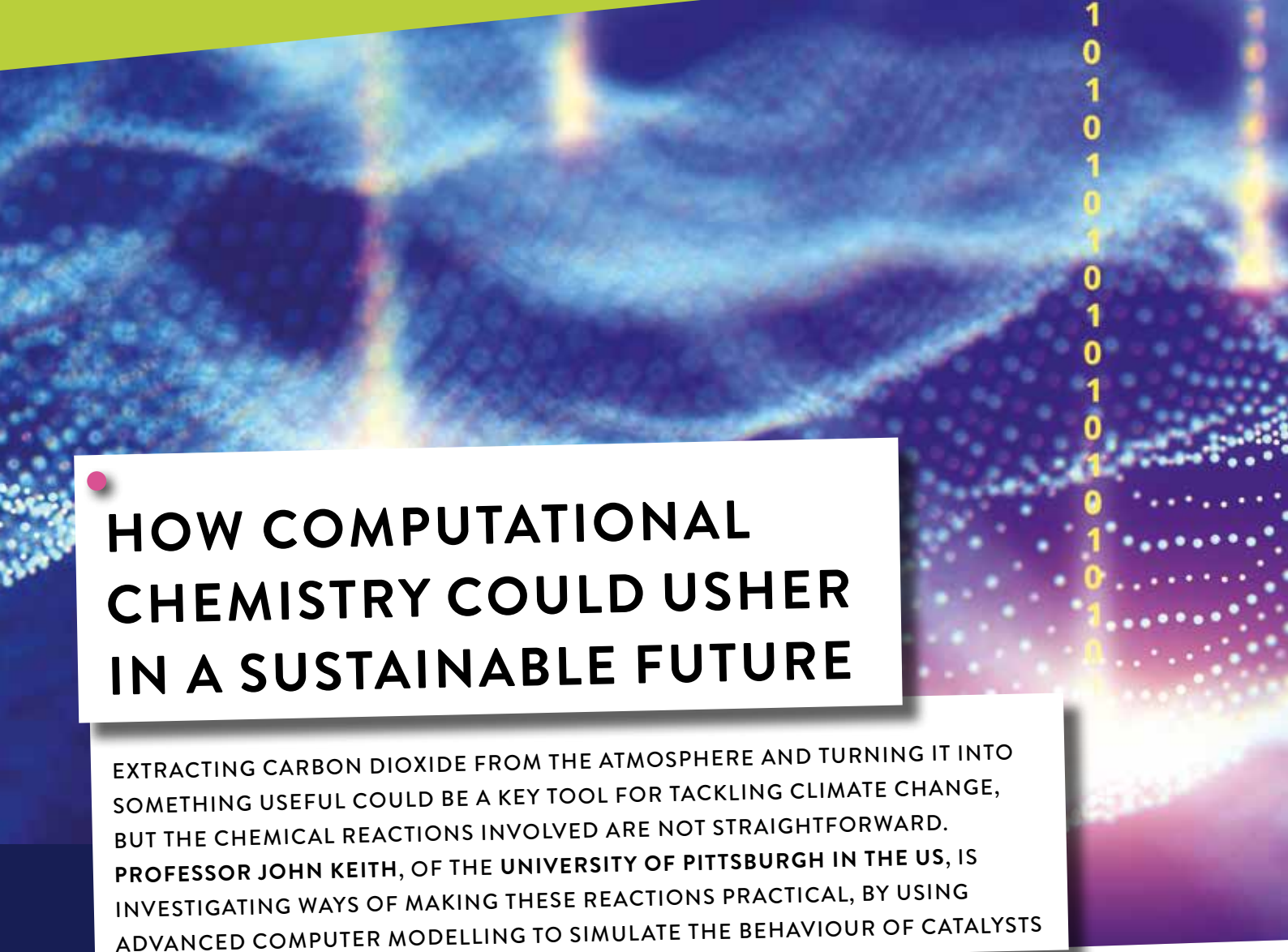
WHAT ATTRIBUTES HAVE MADE YOU A SUCCESSFUL SCIENTIST?

I believe I still have a long way to go before I can be considered a successful scientist, but I believe persistence and working wisely are key attributes for success. We all know that a person who always gives up easily does not deserve victory. However, this is not to say that simply staying longer in the lab and working longer hours is a recipe for success; working wisely and efficiently is often more important than working hard without thinking.

YOU HAVE TAUGHT BOTH CHEMISTRY AND PHYSICS AT HIGH SCHOOL LEVEL. WHAT DID YOU GAIN FROM THESE EXPERIENCES?

Teaching is extremely interesting to me and allows me to gain a deeper understanding and appreciation for what I have learned. Often, it is only when you are preparing a teaching document that you begin to understand how different it can be between learning by yourself and making others understand. In many ways, it helps to frame your own knowledge when you start to attempt to impart your knowledge to others.

Spectroscopy working in the laboratory at The University of Melbourne. (Credit: Gavan Mitchell & Michelle Gough.)



HOW COMPUTATIONAL CHEMISTRY COULD USHER IN A SUSTAINABLE FUTURE

EXTRACTING CARBON DIOXIDE FROM THE ATMOSPHERE AND TURNING IT INTO SOMETHING USEFUL COULD BE A KEY TOOL FOR TACKLING CLIMATE CHANGE, BUT THE CHEMICAL REACTIONS INVOLVED ARE NOT STRAIGHTFORWARD. **PROFESSOR JOHN KEITH**, OF THE **UNIVERSITY OF PITTSBURGH IN THE US**, IS INVESTIGATING WAYS OF MAKING THESE REACTIONS PRACTICAL, BY USING ADVANCED COMPUTER MODELLING TO SIMULATE THE BEHAVIOUR OF CATALYSTS

TALK LIKE A COMPUTATIONAL CHEMIST

CATALYST – a substance that increases the rate of a chemical reaction without permanently changing itself. Catalysts participate in reactions (they increase rates) and they also decompose over long timescales.

CHEMICAL ENGINEERING – a branch of engineering that investigates industrial chemical reactions and operations

COMPUTATIONAL CHEMISTRY – a branch of chemistry that uses computer modelling to solve chemical problems

ELECTROCATALYST – a catalyst that specifically participates in electrochemical reactions

ENTHALPY – an energy quantity equivalent to the total heat content of a system

ENTROPY – the degree of disorder in a system (when multiplied with the system temperature, it is the remainder of the energy available to do work)

ENZYME – a catalyst produced by a living organism to facilitate a biochemical reaction

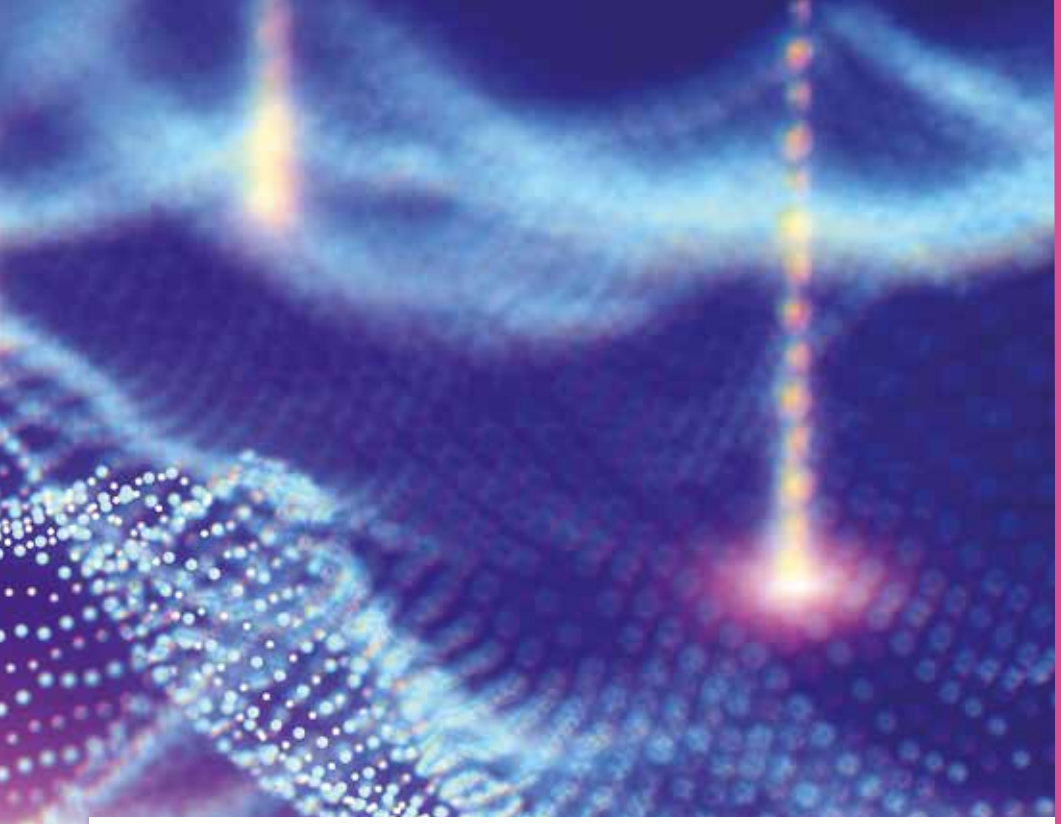
HYDRIDE TRANSFER – the migration of one hydrogen atom with an extra electron from one atom to another

MOLECULAR DYNAMICS – a computational modelling method that analyses random movements of atoms and molecules

QUANTUM MECHANICS – a branch of mechanics that involves the mathematic characteristics of subatomic particles and their energies

Humanity's reliance on fossil fuels over the past century has had a profound impact on the planet's climate. Mitigating climate change is a key global challenge, and one part of the puzzle could be to recycle carbon dioxide from the atmosphere back into something useful. However, there are issues with this. Burning fuels such as natural gas releases energy (alongside carbon dioxide), but producing a fuel from carbon dioxide requires significant input of energy. "Some scientists are attempting this by channelling heat energy from solar power reactors, but this requires extremely high temperatures that can be hard to work with," says Professor John Keith, an expert in computational chemistry and chemical engineering at the University of Pittsburgh. "Others are using electrical current to activate the reaction, but these processes use far more energy than is ultimately stored in the fuel."

The key to solving this puzzle is finding a good catalyst – a substance that lowers the activation energy of a chemical reaction – so that the reaction happens more efficiently and under less extreme conditions. We use catalysts all the time, both in everyday life and industrial processes, but the right catalyst for large-scale conversion of carbon dioxide remains elusive.



PROFESSOR JOHN KEITH

R.K. Mellon Faculty Fellow in Energy, Associate Professor, Department of Chemical and Petroleum Engineering, University of Pittsburgh, USA

FIELD OF RESEARCH

Computational Chemistry & Chemical Engineering

RESEARCH PROJECT

Using computational chemistry to simulate catalysts that could drive reactions for removal of carbon dioxide from the atmosphere.

FUNDER

National Science Foundation

This work is supported by the US National Science Foundation (CBET-1653392). Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

HOW COMPUTATIONAL CHEMISTRY CAN HELP

"Computational chemistry is a way of calculating the energy within any system of atoms by modelling quantum mechanics on a computer," says John. "It's like a special kind of movie camera. We use computational chemistry as a 'camera' to take snapshots of important points along a reaction path of a known catalyst, and each snapshot contains the energy at those points. We can then take snapshots at the same points for any new theoretical catalyst and see if energies indicate that it should perform better."

There are two benefits to using computational chemistry for this process. Firstly, the models may not be perfect, but they provide useful comparisons of catalysts that can help uncover how they function and give insights into what more effective catalysts might look like. Secondly, it is usually much simpler and cheaper to model catalysts on a computer as opposed to making them and performing experiments in the real world. Computer modelling has a rapidly growing role to play in uncovering catalysts for sustainable processes.

BEHIND THE MODELS

John's computer models explain how much energy a particular system of atoms has. The chemical energy of any system (i.e. the 'Gibbs free energy') consists of two components: energy due to stored heat (enthalpy, which is modelled well with quantum mechanics) and energy due to disorder (entropy, which is modelled well using molecular dynamics). Understanding either is challenging in its own right, but most chemical problems can usually be approximated by focusing on one approach and cutting corners on the other.

"Catalysis can get very complicated though, and sometimes we need to focus on both enthalpies and entropies, and that makes for challenging computer simulations," says John.

Computational simulations bring other challenges too. "For starters, we never really know if and when our models are correct, so it's important that we work with scientists doing real-life experiments and share knowledge," says John. "Additionally, the more complicated the system, the more powerful the computer we need. We are sometimes limited in what we can study by the resources we have available."

NOVEL ELECTROCATALYSTS

John works specifically with electrocatalysts, which are catalysts used for electrochemical reactions. The electrocatalysts he studies have quite a unique feature. "Conventional electrocatalysis usually occurs with one proton transfer or electron transfer at a time," says John. "However, in nature we often see enzymes (biological catalysts) transferring one proton with two electrons all at once in a process called a hydride transfer."

Despite hydride transfers being very common in biology and some areas of chemistry, they are uncommon in electrocatalysis. John's work involves deciphering how to make these electrocatalysts switch from conventional electrochemical steps to hydride transfer steps, which could make electrochemical processes more efficient.

LOOKING FORWARDS

"We now have a much better idea about how to model conventional and unconventional reaction pathways," says John. The data that John and his team have collected so far suggests that persuading electrocatalysts to switch to hydride transfer modes is possible, but it might not be as easy as originally hoped. That is the nature of scientific research, and John, tenacious as a scientist needs to be, is confident that the methods developed and lessons learned from fundamental research will have far reaching applications in the future.

"Our next step is to continue improving our computer models and share knowledge," says John. "Our simulation methods can still be used to understand carbon dioxide recycling, or they can help us make biodegradable plastics, fertilizers, and disinfectants more sustainably."

The future will pose many challenging questions – will you join John in the world of computational chemistry and help to answer them?

ABOUT COMPUTATIONAL CHEMISTRY

Computational chemistry uses computer simulations to solve chemical problems. It involves incorporating theoretical chemistry methods into computer programs, which can then calculate the characteristics of molecules of interest. Dr John Keith explains more about his area of expertise.

WHAT DO YOU FIND MOST REWARDING ABOUT YOUR WORK?

I just love all the interesting information we can obtain simply by using a computer to watch and analyse simulations. I imagine it is like how ancient people felt when visiting an oracle. I get jazzed working with other scientists and engineers, getting our brains in sync to make a positive change in the world.

WHAT HAS LED YOU TO THIS POINT IN YOUR CAREER?

My current place is the result of many incremental steps. My undergraduate research project involved modelling gas phase chemical reactions, while for my Ph.D. I worked on modelling chemical reactions in solution. Since then, I modelled increasingly complex chemical reactions. Every experience added a new tool into what is now a big toolbox, and that enables me to analyse just about any kind of chemical reaction mechanism that comes my way.

WHAT OTHER AREAS OF RESEARCH HAVE YOU EXPLORED?

I'm extremely fortunate to get to study so many different and interesting topics. My group has received funding to study electrocatalysis for renewable chemicals, how to improve anticorrosion coatings, and how to make better consumer chemicals. Now, I'm working with colleagues to make better vaccines. This all works because my formal education was in physical chemistry, but I work alongside other chemists, physicists, mechanical engineers, materials scientists and medical researchers. Strong engineering programmes recognise that the most difficult problems need diverse thought to solve them, and so they form skilled teams within their departments and encourage inter-departmental collaborations.

WHAT CHALLENGES WILL THE NEXT GENERATION OF COMPUTATIONAL CHEMISTS FACE?

The field is evolving rapidly. Problems recently thought to be insurmountable, such as predictive models for protein folding, are now being solved using artificial intelligence and machine learning. Some are optimistic that quantum computers will allow computational chemistry to completely revolutionise the pace of scientific discovery. In the meantime, next-generation computational chemists should prepare to ride these waves by getting trained up and balancing the core maths and sciences with humanities, to ensure that these powerful tools are being used for good.

HOW TO BECOME A COMPUTATIONAL CHEMIST

- Computational chemistry is sometimes offered as an advanced undergraduate physical chemistry course and, as John mentions, can be approached from a variety of directions, such as through studying chemistry and starting undergraduate research early. According to QS World University Rankings, the top universities for chemistry are MIT, Cambridge, UC Berkeley, Stanford, and Harvard. Many universities have experts in computational chemistry to learn from and John is proud to have studied at Caltech (the California Institute of Technology).
- Most opportunities to experience work in computational chemistry involve prior knowledge gained through undergraduate study or cooperative internships. For instance, pharmaceutical companies such as GlaxoSmithKline, AstraZeneca, and Merck offer computational chemistry placements for current undergraduates.
- According to PayScale, the average salary for a computational chemist in the US is $101.7k.

PATHWAY FROM SCHOOL TO COMPUTATIONAL CHEMISTRY

John recommends learning subjects like maths, statistics, physics, chemistry, computer science and programming. He also says these should be taken alongside social sciences and humanities for a well-balanced education.

At university, John says that maths is extremely important for computational chemistry, especially calculus, differential equations and linear algebra. Maths, in addition to studying or researching chemistry, biology, materials science or chemical engineering, helps round out the necessary skillset.

John emphasises that computational chemistry is evolving fast – discrete maths, probability, data science, machine learning, artificial intelligence and new computing architectures are all becoming increasingly prominent. He believes that quantum computing may also revolutionise the field in future decades.

Artwork Reproduced from: Y. Basdogan and J. A. Keith, Chem. Sci., 2018, 9, 5341 DOI: 10.1039/C8SC01424H, Published by The Royal Society of Chemistry.

HOW DID JOHN BECOME A COMPUTATIONAL CHEMIST?

WHAT WERE YOUR INTERESTS AS A CHILD?

I went through phases of being obsessed with video games and sports (with little success), but my most major investments as a child were in schoolwork and music lessons. I am a classically trained cellist from a musical family, and I still try to play whenever I can. Music led to great friendships, and I have no regrets.

WHO INSPIRED YOU TO BECOME A SCIENTIST?

My maternal grandfather was a refugee from the Russian revolution of 1917. His version of the American dream involved him becoming a ballistics engineer for the US Army. His daughters and grandchildren all entered the sciences, so I am continuing a family tradition. Personally, I was helped by great teachers at school in central Minnesota and my undergraduate liberal arts college. My undergraduate research mentor taught me that quantum mechanics can answer many interesting scientific problems, and I never looked back after that.

WHAT ATTRIBUTES MAKE YOU A SUCCESSFUL SCIENTIST?

I have decent organisation, time-management and academic background, but my strongest attribute is probably my tenacity – I don't give up on an important problem and can approach obstacles from different angles. It helps to have friends and colleagues in different areas to discuss ideas with and learn from. In the end, like any skill, what one needs will improve with time and practice. Weaknesses should be strengthened, but the pursuit of perfection should not stop progress.

HOW DO YOU OVERCOME OBSTACLES IN YOUR WORK?

It's a gradual process. I will contemplate an obstacle for hours to weeks at a time and wait for inspiration to strike! I'll then bounce ideas off family, friends and colleagues for outside perspectives. It's critical to make theories understandable to non-experts. I then try to carve out time to dig into the details with books and literature and woodshed the theory until I hit another wall – and then I repeat the process.

WHAT ARE YOUR AMBITIONS FOR THE FUTURE?

I want to keep doing cutting-edge research, make education better and more equitable, help train a diverse scientific workforce, and undertake meaningful service projects for my community. My job as a professor gives me a lot of flexibility. For next year, I am contemplating how to disrupt the norms of computational catalysis design; how to launch an educational bridge programme to bring diversity into chemical engineering graduate programmes; and I might be able to launch a start-up company for designing environmentally friendly chemicals. I also aspire to be a good husband and dad.

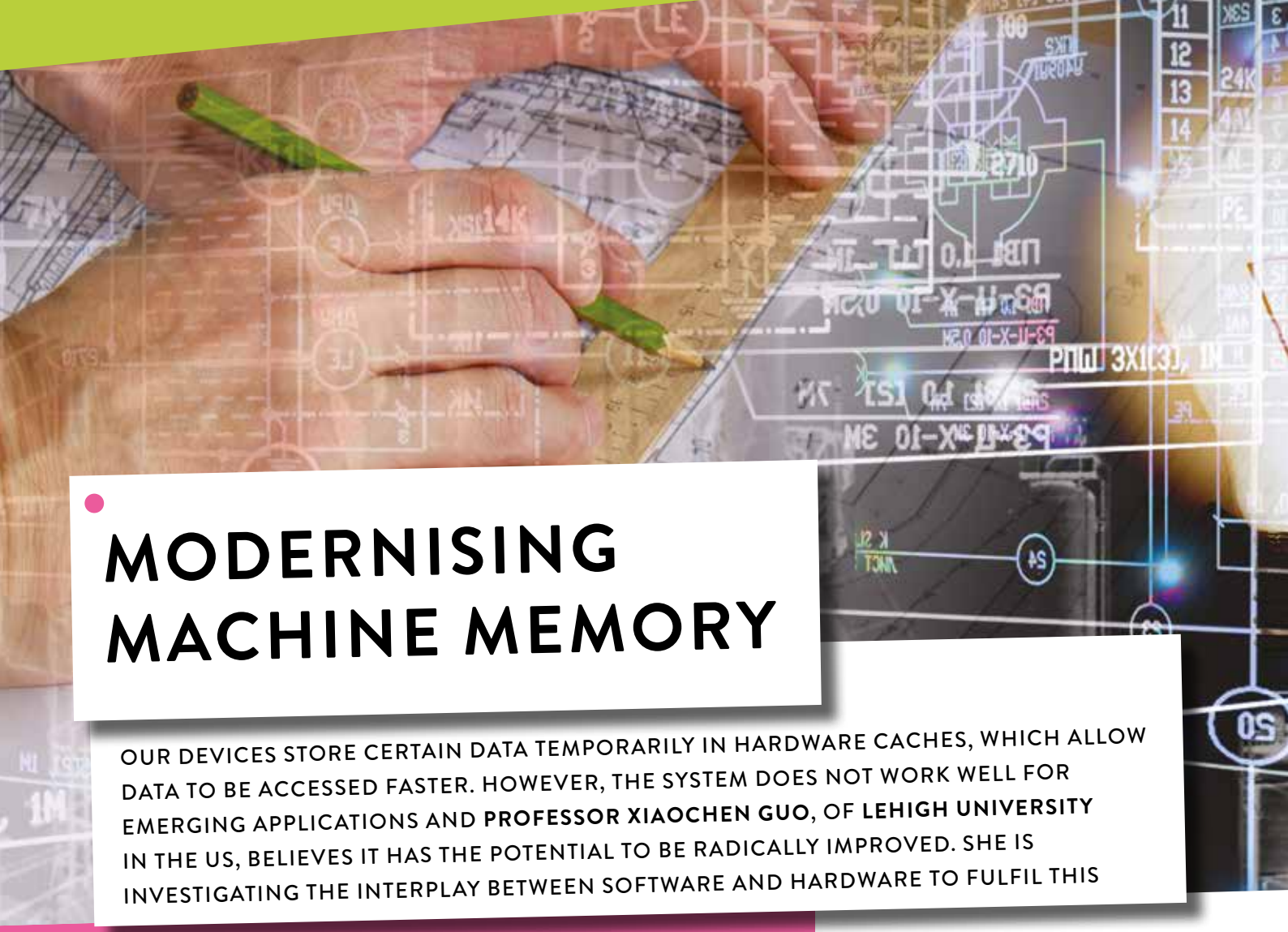
JOHN'S TOP TIPS FOR STUDENTS

01 Focus on finding mentors you can question and learn from daily. They may open new doors that you didn't even know existed.

02 Never be afraid to ask questions, but never rely on one opinion or answer alone.

03 Any craft requires time and dedication, but don't forget your family, friends, and hobbies.

Professor John Keith uses advanced computer modelling to simulate the behaviour of catalysts.



MODERNISING MACHINE MEMORY

OUR DEVICES STORE CERTAIN DATA TEMPORARILY IN HARDWARE CACHES, WHICH ALLOW DATA TO BE ACCESSED FASTER. HOWEVER, THE SYSTEM DOES NOT WORK WELL FOR EMERGING APPLICATIONS AND **PROFESSOR XIAOCHEN GUO**, OF **LEHIGH UNIVERSITY** IN THE US, BELIEVES IT HAS THE POTENTIAL TO BE RADICALLY IMPROVED. SHE IS INVESTIGATING THE INTERPLAY BETWEEN SOFTWARE AND HARDWARE TO FULFIL THIS

TALK LIKE A COMPUTER ENGINEER

CACHE: A computer component that stores data, so that future requests for data can be fulfilled faster.

GRANULARITY: The breaking down of larger tasks or data into smaller tasks or data.

LOCALITY: The tendency of a processor to access data from a neighbouring memory location (i.e., spatial locality) or to repeatedly access the same data in a short time frame (i.e., temporal locality).

MACHINE LEARNING: Computer algorithms that improve themselves automatically through identifying patterns for increased efficiency.

MAIN MEMORY: A computer component that stores data, which can be addressed by the processor. Data have to be placed in main memory to be used by programs. Main memory can hold more data than hardware caches.

METADATA: Data that gives information about other data.

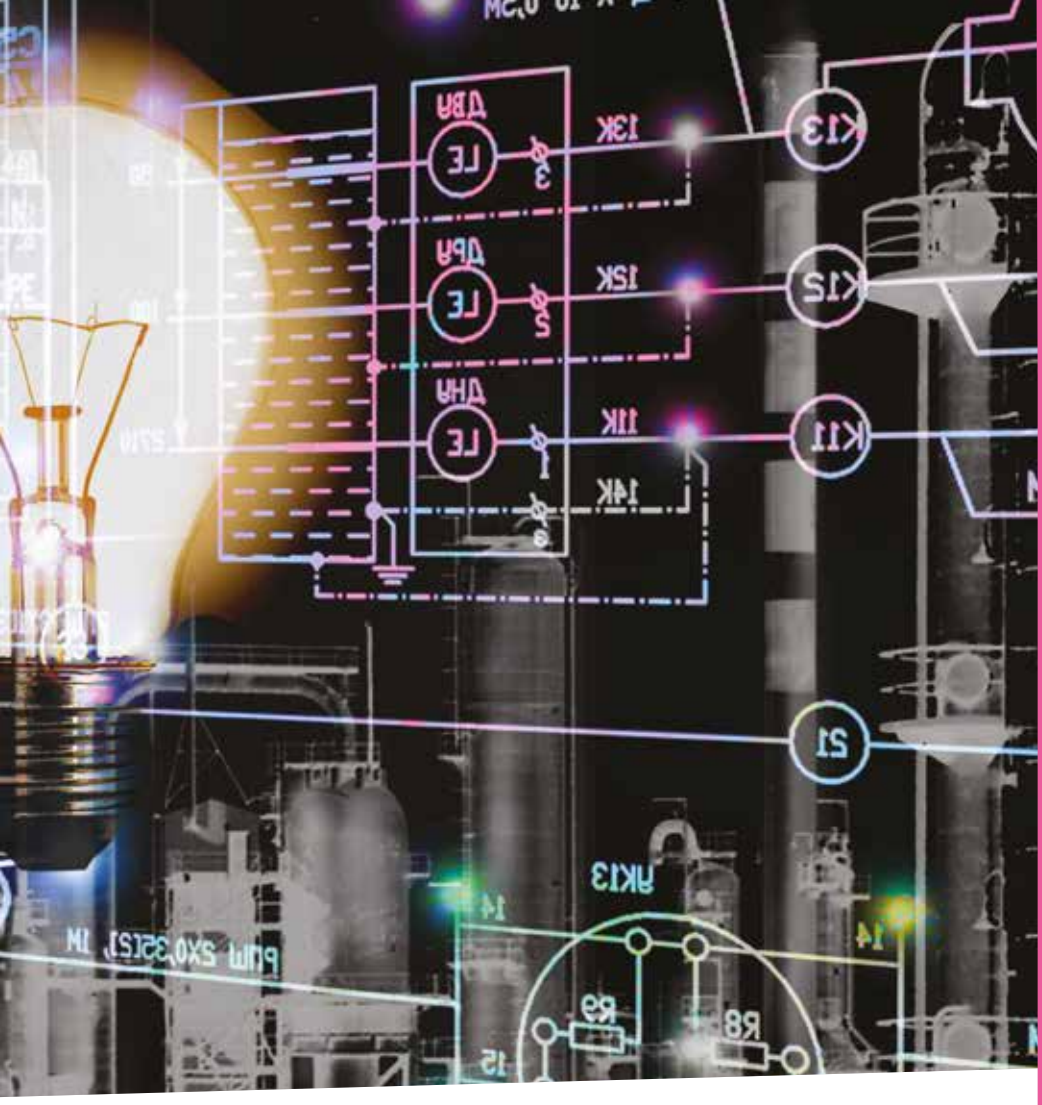
Leaps forward in data access are perhaps the defining technological advancement of the 21st century so far. From social media to streaming, we are able to access vast quantities of data at the tap of a touchscreen. Such wealth of content was barely imaginable even a couple of decades ago. As well as directly improving our daily lives, this means that researchers have access to larger and more complex data sets than ever before, which unleashes new opportunities for science.

However, the technology is still relatively new, and there is plenty of room for improvement. Dr Xiaochen Guo works at the P. C. Rossin College of Engineering and Applied Science at Lehigh University, which is situated in Bethlehem in the US. She and her team are busy revamping the way that memory systems work, to make them work better and more efficiently for big data applications.

MEMORY TROUBLE

"Current memory systems are designed for programs with good locality," says Xiaochen. "This means programs where neighbouring memory locations are accessed repeatedly in a short period of time." These data will be stored in the system's cache. The cache is a hardware structure placed directly on the device and means that the device does not have to repeatedly access the same data from the main memory or the internet. It is designed to speed things up and reduce the processing power required. For instance, if you watch a video of a cat falling over on Instagram, the second time you watch it will be from your device's cache. This is why when the WiFi cuts out when you have an app open, you can often still access a few photos and videos that had already been stored in the cache.

However, there is an issue with this. Although we sometimes like to watch the same video over and over again, modern-day browsing habits are more



PROF XIAOCHEN GUO

Lehigh University, P.C. Rossin College of Engineering and Applied Science
Bethlehem, USA

FIELD OF RESEARCH

Computer Engineering

RESEARCH PROJECT

Revamping computer memory systems for efficient data movement

FUNDERS

National Science Foundation, Lehigh University, US Department of Energy

likely to involve flitting between different apps and accessing a wide variety of content. Storing all this in the cache is pointless if it is never going to be accessed again. "Moving these useless data wastes energy and bandwidth, meaning that current memory systems need to be redesigned, especially as programs advance in complexity," says Xiaochen.

CACHE-22

"We are designing memory and cache architectures that are intelligent enough to avoid moving and storing useless data," says Xiaochen. Traditionally, this involves building systems that can support smaller access granularities – in other words, breaking down the data block received into smaller and more accessible pieces. Then, the hardware can decide which bits to keep and which to discard, rather than keeping the whole chunk. However, to do this involves introducing metadata, which is the 'overseer' used to tag which small pieces are in the cache. When using smaller access granularities, the proportion of metadata with respect to the actual data will increase, and this means that the total amount of data and metadata might not be reduced compared to a larger granularity.

Solving this conundrum involves minimising both the amount of useless data in the cache and its associated metadata. The best way to reduce useless data is to anticipate what data will be useful. And to reduce metadata, common patterns among different metadata can be identified to compress the information. Both can be achieved by analysing the user's past habits.

ANTICIPATING NEEDS

"It can be difficult for hardware to anticipate which data are going to be requested next," says Xiaochen. "This is because hardware processes instructions one by one without knowing the high-level intention of the program." Her team's designs allow the programmer to pass on more information about potential user behaviour to the hardware, such that the hardware can predict better. This not only increases performance and available space in the cache, but also saves on energy expenditure.

"We envision this type of expressive hardware/software interface to be more common in the future," says Xiaochen. "This will involve large changes to programming languages, which will allow programmers to better optimise software."

CHALLENGES

Currently, as might be expected, machine learning applications take up a lot of data. It is a complex task that they are doing, after all. Cleaning up this process by eliminating ineffective tasks is a key challenge for tech companies interested in this area.

"This project is pushing me out of my comfort zone," says Xiaochen. "We had to think outside the box to make our new programming interface able to make accurate predictions."

Xiaochen and her students at Bethlehem, Pennysylvania.

ABOUT ELECTRICAL AND COMPUTER ENGINEERING

As its name suggests, electrical engineering is the branch of engineering that tackles the technology of electricity. As so much of modern society involves electricity, this has rapidly become a very broad field, covering everything from miniscule gadget components to the inner workings of power stations.

Computer engineering is a related field that covers the intersection between electrical engineering and computer science. Specifically, it is involved in the development of computer hardware and software, such as microprocessors, sensors and circuits.

THE DRAWS OF THE DISCIPLINE

"I was inspired to work in this field by the past success of the computing industry," says Xiaochen. "The capabilities of computing have increased exponentially, which has led to tremendous social and economic impacts. I am motivated to contribute to this industry to further increase these capabilities, helping others to solve big problems."

Xiaochen received the coveted National Science Foundation CAREER award for this project. "I am honoured to receive this award, and to be recognised by the community," says Xiaochen. "It is an award for early career researchers and is a great way to help people like myself progress in the field."

INTO THE FUTURE

"I plan to continue to innovate on improving energy efficiency for computer systems," says Xiaochen. "I am also going to investigate new computing paradigms. One particularly intriguing project involves using living neurons as computers!"

The future is bright for the discipline, which is ever-expanding as technology becomes ever-more integrated into our daily lives. "Attracting young people into the area is key," says Xiaochen. "Electrical and computer engineering tends to be more abstract compared to other fields of engineering, and often more challenging too, given how diverse it can be – but it's always extremely worthwhile."

HOW TO BECOME AN ELECTRICAL ENGINEER OR COMPUTER ENGINEER

- According to Top Universities, the best universities in the world for electrical and computer engineering are MIT, Stanford, University of California-Berkeley, Cambridge and ETH Zurich.
- A number of organisations offer apprenticeships in electrical and computer engineering. These can include companies designing computers and those working on smart phones, self-driving cars or robotics.
- Lehigh University, where Xiaochen works, has a CHOICES programme to introduce engineering and science to female middle school students. They also host the Lehigh Valley Science and Engineering Research Fair, which aims to increase awareness about STEM subjects amongst high schoolers.
- According to Indeed, the average salary for a computer engineer in the USA is $93,000 per year.

PATHWAY TO BECOME AN ELECTRICAL ENGINEER OR COMPUTER ENGINEER

- Xiaochen recommends physics and maths as the most important subjects to take at school to pursue a career in electrical or computer engineering.
- Xiaochen also recommends learning programming early on, a skill that tends to be crucial for her field.
- Electrical engineering is a more common degree than computer engineering. Both of these, or a degree in related fields (such as engineering or computer science), can lead to a career in Xiaochen's field.

Students nominated Prof Guo for a Mentorship Appreciation Award.

HOW DID PROF XIAOCHEN GUO BECOME A COMPUTER ENGINEER?

WHO INSPIRED YOUR CAREER?

I have been very lucky to have the support of many people, including my family, friends, teachers and mentors. I still remember one of my grade school teachers who told me I should become a scientist, which gave me the confidence to pursue engineering. Later on, my PhD advisor said that I had the characteristics needed to become a good college professor, which encouraged me to pursue an academic career. Being recognised you can do something is very powerful!

WHAT MAKES A SUCCESSFUL ENGINEER?

Logical thinking, resilience, and the ability to collaborate with others have given me some advantages. Engineers need to be analytical, good at making connections and able to draw logical conclusions. It's important to remember that many things can go wrong in engineering projects! Figuring out how to turn a failure into success is key. Additionally, being able to communicate with people with differing areas of expertise will open many more opportunities.

WHAT HAVE BEEN YOUR PROUDEST ACHIEVEMENTS TO DATE?

My students are a fantastic legacy. I have seen them solve difficult problems I did not know the answers to, come up with great ideas and get internships and jobs at well-known companies.

HOW DO YOU SPEND TIME OUTSIDE OF WORK?

I have always enjoyed sports. Nowadays, I am an endurance runner. I run almost every day and it is a good way to 'switch off".

XIAOCHEN'S TOP TIPS FOR STUDENTS

01 It's fine to not know what you want to do, but you have to keep searching until you find it. I didn't know I would enjoy computer engineering and found it through exploring different subjects.

02 Being different is not a problem. Always be true to yourself. Doing a PhD set me aside from my peers, but I enjoyed focusing on what I found important and not feeling I had to fit in.

03 Learn to program as early as you can. As well as its directly applicable uses, learning to program is great training for logical thinking and problem solving.

Xiaochen at Lehigh University.

DISCOVERING HIDDEN PATTERNS IN DATA

ONE OF THE GREATEST CHALLENGES IN MODERN SCIENCE IS HOW TO GET USEFUL CONCLUSIONS FROM MASSIVE DATASETS. **DR ERIC CHI**, OF **NORTH CAROLINA STATE UNIVERSITY** IN THE US, DEVELOPS INNOVATIVE WAYS TO DISCOVER THE INFORMATION HIDDEN WITHIN DATA, HELPING WITH A RANGE OF SOCIETAL ISSUES

TALK LIKE A DATA SCIENTIST

DATA – anything that can be recorded or measured

DATA CLUSTERING – dividing data points into groups, where data points within each group are more similar to each other than those in other groups

DATA CUBE – a multi-dimensional array of values

INFORMATION EXPLOSION – the rapid increase in the amount of available data, brought about by technological progress in areas such as computing power and the internet

NEUROSCIENCE – the scientific study of the nervous system

OPEN SOURCE – software where the original source code is made freely available

STATISTIC – computed summarisation of data that helps interpret the data

VARIABLE – a factor whose value changes in a scientific experiment

In our modern age of computing, we have the tools to collect massive amounts of data on all kinds of subject matters, but the challenge is building the tools to interpret this data to draw meaningful conclusions. At the Statistics Department of North Carolina State University, Assistant Professor Dr Eric Chi is tackling this issue and using mathematical concepts to tease information out of complex datasets.

WHEN DATA GETS COMPLICATED

One of Eric's current projects involves finding patterns in data cubes. An example of a data cube is a three-dimensional dataset – each dimension could have multiple variables. Generally, humans are better at seeing patterns in two dimensions, such as a graph with x and y axes. When we add more dimensions, things start to get complicated.

Neuroscience is one scientific field where new recording techniques have meant that the quantity of data available to us has exploded in recent decades. For instance, the activity of neurons (nerve cells) in the brain can be measured using three dimensions: time, the specific neuron involved, and the experimental conditions involved. This can be stored in three-dimensional space to form a data cube. "We've been working on methods to analyse such data," says Eric. "We want to see if we can identify neuronal firing patterns and how they change over time, under different experimental conditions. This will help neuroscientists better understand the brain."

An example of a 3-way multidimensional array or data cube.

SORTING BY SIMILARITY

"The idea of clustering is to group a collection of datapoints in such a way that members in the same group are very similar to each other, while very different from members in other groups," says Eric. This helps us to visualise data in separate 'clusters', which then helps us to understand the data. For instance, if you collect data on environmental and genetic factors of individuals, you can cluster these observations to make progress towards understanding who is more likely to get a certain disease and to gauge how much individuals might be at risk. Clustering is an example of exploratory data analysis – a first step in developing models for making predictions that can guide clinical decision making.

It can also help us to understand more complex data. "Suppose you work for an online streaming

platform," says Eric. "You have data on your customers and on the films you host, and you want to group your customers so the algorithm can recommend movies to them based on their preferences." This involves clustering of data along two different dimensions: the type of customer, and the type of movie. This is called biclustering. It is useful because not only can you identify that a particular customer has similar movie selection habits to others, you can also identify movies that fit within that category to recommend to them.

PATTERNS IN SENATE VOTING BEHAVIOUR

"Imagine you have a three-dimensional object and shine a light onto it, so it casts a shadow," says Eric. "This shadow is a two-dimensional projection." Sometimes, we can have a fair idea what an object looks like just from its shadow. Eric uses the equivalent of this 'dimension reduction' technique to make datasets easier to understand.

"Take the US Senate's roll call voting data, for example," says Eric. "Senators will vote 'yes' or 'no' on a huge array of different measures such as social, military and environmental concerns. At first it may seem these issues have little in common, but there's actually a lot of structure to how senators vote on them." Eric can use dimension reduction to plot these voting patterns of different senators in two-dimensional space. Perhaps unsurprisingly, the results show that senators' voting patterns tend to be most similar to others within the same political party. More interestingly, however, the results also reveal an axis that identifies within party variation for both parties.

For instance, if one senator is 'close' to another on the two-dimensional projection, chances are they will vote the same way. This same idea can be used for all sorts of scenarios. For instance, scientists might be interested in how a new pharmaceutical chemical is likely to behave. By using dimension reduction, they can compare its characteristics (e.g. structure, composite atoms, etc.) to existing chemicals. It is likely to behave similarly to those it is 'close' to on the plot.

DR ERIC CHI

Assistant Professor, Statistics Department, North Carolina State University, USA

FIELD OF RESEARCH

Statistics and Data Science

RESEARCH PROJECT

Developing statistical methods for exploring and analysing complex datasets.

FUNDER

National Science Foundation

This work was supported by the NSF, under award numbers DMS-1752692 and DMS-1454942. The contents are solely the responsibility of the authors and do not necessarily represent the official views of the NSF.

Q&A WITH JUSTIN LUMPKIN – ONE-TIME PARTICIPANT AND NOW MENTOR FOR THE DATA SCIENTISTS IN TRAINING (DST) PROGRAMME

WHAT WERE THE MAIN ACTIVITIES YOU TOOK PART IN ON THE DST PROGRAMME?

The DST programme is all about exposing teenagers to the field of data science. I had the opportunity to interview data scientists working in different fields, as well as touring SAS Institute's (a leading data and analytics company) facility in Cary and having conversations with employees about their career paths. During the school year, we met once a month to work on a data analysis project, which culminated with the North Carolina Junior Science and Humanities Symposium.

WHAT WAS YOUR SPECIFIC PROJECT?

I worked with one other student and Dr Chi. We analysed the patterns on assaults committed in the town of Raleigh, in terms of where they took place and at what times. We used some analytical methods to capture the underlying patterns and create a simulated dataset that was much smaller. This allowed us to create more meaningful, less cluttered visualisations of the data.

WHAT DID YOU GAIN FROM TAKING PART IN THE PROGRAMME?

I found the career guidance offered really beneficial in understanding what a data science career means. Ironically, it was helpful to learn that there isn't any one path, but rather many different routes you can take. There are data scientists with a range of different qualifications, working on hugely varied projects, from streaming service recommendations to the patterns of degenerative diseases.

WHAT DO YOU FIND CHALLENGING ABOUT DATA SCIENCE?

It can be difficult to figure out how to start a project, since the overall process seems so daunting. I think that getting used to the independence of the workflow was challenging, but I am very proud of our accomplishments. One of the most important aspects of data science is finding ways to represent data meaningfully, so I found the visualisation part of the process really rewarding. It makes it clear that the process is not just an academic exercise, but has potential to bring real benefits to the world.

HOW DO YOU FIND NOW BEING A MENTOR?

Initially, my role was to bring the perspective of a student into the curriculum design of future DST programmes. In light of the Covid-19 pandemic, we wanted to work on a project that has more of a direct impact on students. Our team is working on a web application that can be used by teachers of computer science or statistics. It aims to help students determine which variables in a dataset are most useful for creating a statistical model.

WHAT'S NEXT FOR YOUR CAREER?

I am going to the University of Maryland at College Park in the autumn to study computer science. I plan to pursue a career in data science, and hope to use my skills to solve problems in the urban planning field.

ABOUT DATA SCIENCE

WHY IS DATA SCIENCE NEEDED?

Data science is a broad discipline that focuses on extracting knowledge from datasets, especially large or complex ones. The 'information explosion' of recent decades means that it has become a rapidly expanding and increasingly crucial field that many other fields of science rely upon to find meaningful conclusions.

"The methods I develop can be used as part of a complex data analysis process," says Eric. His work is one piece of the puzzle; good science is heavily dependent on collaboration, and he has worked with scientists from a huge range of disciplines to help them make important breakthroughs. "It's very rewarding to be part of the process," he says.

HOW HAS INFORMATION SHARING HELPED OTHERS?

Collaboration, the sharing of ideas and methods, and interdisciplinary approaches are often vital in research – Eric is certainly one researcher who is keen to ensure his work can aid others. For instance, his code on biclustering is open source, which means that it is freely available on the internet and other people can easily incorporate the method into their own work. This code was recently used by cancer researchers to identify complicated relationships between certain genes and the likelihood of certain combinations of diseases developing. "One of the things I love about the work I do is that it combines beautiful mathematics with practical engineering to develop reliable tools for making scientific discoveries."

WHAT DOES THE DATA SCIENTISTS IN TRAINING (DST) PROGRAMME OFFER PARTICIPANTS?

"I got into this career through an interest in mathematics, but that's not the only route, by a long way," says Eric. In collaboration with Dr Mary Ann Leung of The Sustainable Horizons Institute, he designed - and co-led with fellow NCSU Statistics faculty member Dr Ana-Maria Staicu - a programme that helps prospective students explore the various ways to pursue a career in data science. "One activity involves participants interviewing a data scientist," says Eric. "These scientists may work in academia, industry, or government. Participants find out about their career pathway and share what they've learnt with the rest of the group."

Participants also work on a year-long team-based research project that allows them to get hands-on with data science methods. "One thing I like about data science is that a lot of strategies are quite intuitive," says Eric. "This means that a curious high school student can readily grasp the idea behind many techniques. The goal of this programme* is to spark curiosity and give participants guidance on future choices in their education."

In addition to the NSF, the programme gratefully acknowledges receiving logical support and planning from The Science House at NCSU, computer resources from NCSU's College of Sciences Information Technology, and financial support from The Statistical and Applied Mathematical Sciences Institute, (SAMSI) and RStudio.

HOW TO BECOME A DATA SCIENTIST

- As Eric mentions, data scientists are needed for a massive range of disciplines, not only within academia but also in business management, marketing, tech, and governance.
- There are a few universities that teach data science at undergraduate level. In the UK, this includes Russell Group universities such as London School of Economics, Warwick, and Exeter.
- University courses in other subjects, such as mathematics, are also recognised routes for a career in data science. According to Top Universities, the best institutions for studying mathematics are MIT, Harvard, Stanford, Cambridge and Oxford.
- According to Glassdoor, the average data scientist in the US makes $113,300 a year.

PATHWAY FROM SCHOOL TO DATA SCIENTIST

- Eric says that there are many different ways to pursue a career in data science. Studying statistics, mathematics, computer science or electrical engineering at university are all very viable options.
- At high school, useful subjects to take to prepare for degrees like these include mathematics, statistics and computer science.
- It is always worth exploring extracurricular means to increase your experience. There are a wide range of programmes that can help with this, such as the DST programme that Eric designed. Others include the MIDAS Data Science Summer Camp in Michigan, the Data Science Academy at Georgetown University, and the Data Science for Women Summer Camp in Ohio State University.

HOW DID ERIC BECOME A DATA SCIENTIST?

WHAT INSPIRED YOU TO CHOOSE YOUR CAREER?

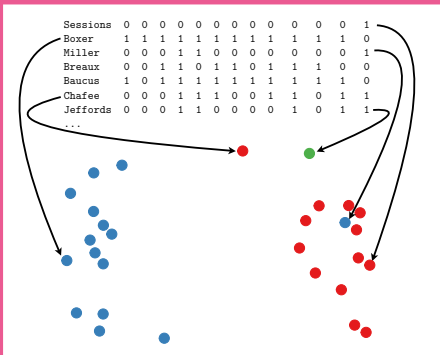
If I had to blame one person for setting me on this career path, it would be my high school geometry teacher! He shared his delight in elegant proofs, with all of his students, and helped me develop my interests and tastes early on.

WHAT SKILLS HAVE YOU FOUND USEFUL FOR YOUR AREA OF EXPERTISE?

Statistics is a very broad field, but my research focuses on machine learning and algorithm development. To get into this particular area, courses like real analysis, linear algebra, and probability are useful for the mathematical side of things. There is also the computing element, where courses on optimisation, coding and software engineering are extremely helpful. Together, these provide a solid foundation for learning more specific skills.

WHAT INSPIRES YOU TO MENTOR FOR THE DST PROGRAMME?

I had a lot of good mentors throughout high school, college, and beyond. I wouldn't be where I am today without them. It's rewarding to play a small part in getting young students interested and curious about maths, statistics and data science.



Principal Component Analysis of Senate Roll Call Data: Yes (1) and No (0) votes of senators on 13 issues (13 dimensional observations) are represented in a 2-dimensional plane. Democratic senators are in blue, Republican senators are in red, and Independent Senator Jeffords is in green.

ERIC'S TOP TIPS FOR STUDENTS

1. Don't be afraid to try new things and to fail sometimes.
2. There are a lot of good free resources out there that will help you with your career. For instance, a free coding course for Python can be invaluable for getting into machine learning.
3. Take ownership of your future but be patient with yourself. It can take time to figure things out but it's important to explore.

The first cohort of DST participants work on a project during a bootcamp.

CONNECTING THE DOTS BETWEEN SCIENCE AND BUSINESS

SCIENCE AND BUSINESS ARE OFTEN TREATED AS TWO SEPARATE DISCIPLINES, WHICH LEADS TO PROBLEMS. SCIENTISTS MAY LACK THE BUSINESS SENSE TO CONVERT THEIR RESEARCH INTO SOMETHING PRODUCTIVE, WHILST BUSINESS PROFESSIONALS MAY LACK THE SCIENTIFIC KNOWLEDGE NEEDED TO MAKE EVIDENCE-BASED DECISIONS. **WESTMINSTER COLLEGE'S ENVIRONMENTAL PROJECT MANAGEMENT ACADEMY (EPMA)** AIMS TO BRIDGE THIS DIVIDE

Liberal arts institutions prepare students to reason logically, think critically, communicate effectively, and act ethically. However, while STEM graduates often enter the workforce with plenty of knowledge of their area of study, they may lack critical business and project management-related skills, such as communication and leadership skills. On the flipside, graduates of subjects such as business can have highly developed business acumen but can lack the basic scientific literacy that has an important role in the workplace.

Westminster College, situated in Pennsylvania, USA, launched the Environmental Project Management Academy (EPMA) to address this. The EPMA is funded by the National Science Foundation and is run by three professors, Dr Helen Boylan, Dr Alison DuBois, and Mr Brian Petrus, who have combined their diverse areas of expertise to ensure that students leave the EPMA with a well-rounded skillset that prepares them for the working world.

The environmental science course emphasises scientific literacy and the major environmental issues facing our planet. The business administration course develops the competencies and skills needed to effectively manage a project's life cycle by understanding the project's scope, including associated project costs and cohesive team functioning. The cross-disciplinary cluster course also includes a two-hour weekly leadership seminar embedded into the course meeting times, during which students further develop intangible skills (such as communication skills and training in team dynamics) that are applicable to the team-based project work.

Through the EPMA programme, students collaborate with community stakeholders as they integrate knowledge of environmental science, project management and intangible skills with project work on environmental issues relevant to the region.

THE IMPORTANCE OF CROSS-DISCIPLINARY LEARNING

"College classes are often taught in isolation and exclusively by discipline," says Dr DuBois. "We wanted to show the inter-connections between environmental science, project management, and leadership. The three of us collaborate in our teaching, so our projects share a common thread through all three disciplines."

Dr Boylan believes that combining these skillsets makes students more desirable as future employees. "Employers in the modern world value collaboration," she says. "The complex problems that we face today, such as climate change, the pandemic or the role of artificial intelligence, require people from different disciplines to collectively solve problems. Our programme teaches students from STEM or business backgrounds how to communicate with each other. The projects require both perspectives, so collaboration is vital."

WHY SCIENCE IS IMPORTANT FOR EVERYONE

"It is my belief that almost all future jobs will require a basic understanding of science and math," says Mr Petrus. "STEM literacy fosters creativity and critical thinking skills, which encourages teamwork and experimentation – important skills in real-world business environments."

The world is also becoming more cross-sectoral, especially as businesses' environmental footprints fall under increasing scrutiny. "Many businesses today are really developing their sustainability practices," says Dr DuBois. "Having a background in STEM alongside business acumen helps create a more well-rounded professional."

A growing reliance on technology also calls for people able to understand what it all means. "In the high-tech, data-driven world that we live in, people need to be able to look at data or figures and make sense of them," says Dr Boylan. "We need to be able to critically analyse conclusions and methodology, which STEM literacy can help with."

EPMA PROJECTS

The EPMA has undertaken three projects so far. Each project examined the underlying science of a topic and the feasibility of its implementation in a real-world setting. They have covered prospective solar panels in the college's borough, collecting and selling

recovered minerals from acid mine drainage and industrial hemp operations.

"The industrial hemp project was my favourite," says Dr Boylan. "Our students developed website content related to the science of industrial hemp and completed a market analysis of potential hemp products. The students learnt about technologies associated with hemp products, such as biopolymers and composite plastics, and also how it could lead to economic growth in our region. This meant there was a real motivation for both students and faculty." Mr Petrus agrees, and mentions how it tied in to changes in federal legislation. "The project aligned with the 2018 Farm Bill and the associated regulatory changes in the industry, namely the legalisation of industrial hemp," he says. "We are seeing the foundations of a multi-billion-dollar industry."

Dr DuBois has a soft spot for another project. "Even though it wasn't as exciting as the hemp project, I really enjoyed investigating acid mine drainage," she says. "I spent a lot of time hiking growing up and this project led to me and the students learning a lot about the environment."

Now, they are getting started on a new project. "This year we are investigating sustainable business ventures into resources such as maple syrup, honey, cash crops and so on," says Mr Petrus. "This is in conjunction with underutilised wooded properties owned by Westminster College."

DR HELEN BOYLAN

Director of the Center for the Environment

FIELD OF RESEARCH

Chemistry and Environmental Science

ROLE

My role is to plan and deliver the environmental science content of the programme. I also develop lab experiences for the students, that help them develop their technical skills. I serve as the point of contact for our community project partners.

INSPIRATION

I grew up next to the Allegheny National Forest. It was my playground and my laboratory. I was fascinated by this environment and the critters it contained, which meant that environmental science appealed to me.

HELEN'S TOP TIPS FOR STUDENTS

Be curious. Ask questions about the world and the people around you. Read up on the things you are interested in. Explore!

Embrace failure. In science, you learn as much – if not more – from your mistakes than you do your successes. Often, science isn't easy. Sometimes you just have to keep trying. Don't be afraid to try new or difficult things – it is always worth it in the end.

DR ALISON DUBOIS

Associate Professor/Director of Graduate School

FIELD OF RESEARCH

Burnout and Compassion Fatigue

ROLE

I teach a 10-week leadership seminar. Students learn about leadership theories and traits, and work on building more effective communication and writing skills. The unique aspect about this part is that students engage in activities that make them feel vulnerable. This helps them to develop a deeper level of self-awareness, in addition to stronger emotional literacy skills.

INSPIRATION

I really love to teach. I get inspired by my students' enthusiasm and risk-taking when they work on difficult tasks. It is motivating to watch the students grow as they stretch themselves intellectually.

ALISON'S TOP TIP FOR STUDENTS

Anxiety is not a bad thing. Choose to get out of your comfort zone and try something challenging.

MR BRIAN PETRUS

Assistant Professor of Business Administration

FIELD OF RESEARCH

Project Management, Human Resource Management

ROLE

I act as a co-investigator for the EPMA project, developing and delivering the portion of the curriculum that focuses on project management. I have found the EPMA programme to be extremely rewarding. In addition to working directly with students, it gives me the opportunity to work alongside two of the college's brightest and most student-centric professors.

INSPIRATION

My father has always been my greatest source of inspiration. He is retired from the Natural Resource Conservation Service and is a true jack-of-all-trades – he has provided me with innumerable life lessons that I often draw upon in the classroom. In all that I do, I strive to be the man that my father has taught me to be.

BRIAN'S TOP TIP FOR STUDENTS

You can spend money and always make it back. When you spend time, however, you never get it back. So, spend your time wisely, doing the things you love and with people worth spending it with.

MEET THREE EPMA STUDENTS

NAME: Samuel Hockenberry

MAJOR: Mathematics/Computer Information Systems (Double Major)

CURRENT ROLE: Lead Analyst - Full Stack Developer at BNY Mellon

EPMA was offered as a cluster course during the spring term of my junior year. It offered a unique experience to work on a collaborative project while also learning about environmental science and project management.

I participated in the project that assisted the New Wilmington Borough on whether implementing solar panels in the community was a worthwhile investment. It required everything you would expect in a real-life work environment: meetings, deadlines, research, communication, and detailed documentation. It was challenging because most of these skills are usually learned outside of the classroom, and some of them were new to me.

This course gave me new insights into the world of renewable energy. Although it would be great to use solar panels everywhere, we simply do not have the technology to fully replace our current electricity infrastructure.

I found that project management is heavily based on two concepts: communication and documentation. These can drive a project to success or can lead it to failure if not utilised properly. Our teams had to keep detailed documentation and open communication throughout the project.

I attribute this course to 'jump-starting' my career. By the time it came to an end, I could understand a project's lifecycle and confidently apply that knowledge outside of the classroom. This helped me every day during my summer internship, which led me to secure the position I am in today.

In the short term, I would like to become a product manager for a project, where the skills I learned in the course would come in useful. In the longer term, I hope to continue my education and receive a Master's degree in Computer Science, and eventually a PhD in Mathematics.

I would advise anyone to take the course! It is the closest students can get to 'real-world' project development outside of the workplace.

NAME: Reilly DeGeorge

MAJOR: Environmental Science

CURRENT ROLE: Industrial Laboratory Chemist

I took the EPMA course because I wanted to further my knowledge in topics related to the environment and project management, and to gain more real-life and hands-on experiences.

I took part in researching industrial hemp, such as its associated agricultural science, the legalisation and regulations surrounding hemp, and the business of selling and distributing hemp products in the US. This class challenged me to use my voice and participate in discussions and meetings. I also learnt how to use new software and effective working within teams.

We collaborated with DON Services Inc. and provided them with information on the hemp industry. Due to the pandemic, we were unable to collaborate with the farmers, but we still got great hands-on experience.

This project has helped me get a better understanding of the environment through learning about real-world situations. We were able to go out and talk directly to the people they affected.

The programme has taught me how to communicate effectively within small teams, how to manage and lead groups of people, how to communicate better, and how to make pivotal decisions.

I am currently working within a small team at an industrial laboratory and am constantly communicating with team members and truck drivers. The EPMA really helped me develop better communication and organisational skills. I am working towards getting my MBA and can see myself following a career in industry or the government, specifically in the environmental field.

I would advise students to get as much real-world experience as they can. The EPMA can grant you many opportunities – use them and learn from them. Build relationships with as many professors and environmental students as you can, because you can really learn a lot from them.

NAME: Zach Fryda

MAJOR: Biology

CURRENT ROLE: Medical Student, LECOM Bradenton

Being a biology major, I had very little exposure to business and project management in academia, so EPMA seemed like the perfect opportunity to learn these skills in a familiar context.

My project involved evaluating the feasibility of implementing solar energy in New Wilmington Borough. The project relied upon the integration of three different perspectives, each of which provided its own set of challenges. Morally, I was challenged to actively think about the impact of my choices and how my sphere of influence affected group dynamics and my leadership qualities. Scientifically, I was challenged to understand the science behind not only solar energy, but the wider field of sustainable energy too. Financially, the project challenged me to appreciate the fiscal responsibilities associated with STEM research and developments.

The project's primary stakeholder was the Borough of New Wilmington and its associated board members. By working with local government officials, we applied educational concepts into actual scenarios. This not only prepared us for similar applications in the future, but also allowed us to expand upon our political skills.

Prior to EPMA, my understanding of sustainable energy was very limited. One of the most enlightening topics we discussed was the environmental impact of manufacturing solar energy. When I took the course in 2017, the environmental impacts of the manufacture of some solar panels was only just offset by the resultant clean energy. This insight taught me to think critically about technologies labelled as clean, and the need to develop surrounding infrastructure as well as the products themselves.

I had practical experience of project management prior to EPMA, specifically through working as a seasonal warehouse manager at a major fireworks store. However, putting academic context to my skills allowed me to improve them immensely and provided me with the framework to extrapolate them to other scenarios.

I credit this course for the sole, most significant growth of my leadership style and personal development. It made me evaluate and improve my actions and contributions as a leader and group member. Although my scientific knowledge grew, it is the leadership techniques I learnt that now help me during my medical school education. I cannot emphasise enough the importance of this aspect of EPMA in helping me succeed as a graduate, medical student, and future physician.

I am currently a second-year medical student and plan on obtaining a Master's of Public Health. After medical school, I hope to become a Paediatric Infectious Disease Physician. I want to impact public health on a global scale. Ultimately, I hope to work for the Centers for Disease Control and Prevention, where I can not only treat patients but can also impact policy that could positively affect people around the globe.

I would advise prospective students to keep an open mind and not only focus on content they deem 'relevant' to their area of study. Had I not fully engaged with every opportunity presented to me, I could have unknowingly shut doors that would help me meet my future goals.

EDITING GENES TO BENEFIT SICKLE CELL DISEASE PATIENTS

DR NATALIA RIVERA-TORRES IS CONDUCTING SICKLE CELL RESEARCH AT THE **CHRISTIANACARE'S GENE EDITING INSTITUTE** IN DELAWARE IN THE US. THE INSTITUTE IS AN ASPIRATIONAL AND SUPPORTIVE COMMUNITY COMPOSED OF PEOPLE AT DIFFERENT STAGES OF THEIR CAREER – ALL OF WHOM DO GROUND-BREAKING WORK

Genes are amazing. They are units of deoxyribonucleic acid (DNA) and carry information that determines the features and characteristics that are passed down to you from your parents, such as the colour of your eyes or the texture of your hair. It is estimated that each cell in the human body contains between 25,000 to 35,000 genes, contained within chromosomes.

Unfortunately, genes sometimes carry an error in their DNA sequence that leads to a person inheriting health conditions and diseases. One of these health conditions is sickle cell anaemia, which affects red blood cells. It is especially common in people with an African or Caribbean heritage and is a serious, lifelong condition. One of the main effects is that red blood cells cannot carry enough oxygen around the body, causing fatigue and shortness of breath. Sickle cell anaemia is incurable, although treatment can help patients manage many of the symptoms.

Dr Natalia Rivera-Torres, based at ChristianaCare's Gene Editing Institute in Delaware in the US, is conducting sickle cell research which relies heavily on gene editing principles. It is hoped that her work will lead to the ability to predict how each person's blood stem cells will respond to gene editing to develop better treatments. Natalia and the team are working to identify the optimal CRISPR molecules that can provide a more universal response to sickle cell anaemia. The aim is to develop a prediction index that will determine the effectiveness of CRISPR-directed gene editing in individual patients.

WHAT IS CRISPR AND WHY IS SICKLE CELL DISEASE A GOOD CANDIDATE FOR IT?

CRISPR is a relatively new technology that can be used to edit genes. It is difficult to overstate the potential importance of CRISPR; it will likely change the world in ways that would have been unimaginable just a few years ago. CRISPR enables scientists to find a specific part of DNA inside a cell, from where it can be altered. One particularly exciting possibility is that genes can be turned on or off without altering the sequence of DNA – this could lead to a world where the genomes of children are changed to prevent diseases such as sickle cell. "Sickle cell disease is caused by a single mutation in the β-globin gene that results in hard distorted red blood cells with a sickle shape. This leads to diverse clinical manifestations with poor quality of life and early death," explains Natalia. "CRISPR has opened the possibility of fixing the single mutation in a more controlled and efficient way than previous gene therapy technologies."

WHAT CHALLENGES DOES NATALIA'S RESEARCH POSE?

It is believed that genetic diversity among individuals changes the way human cells respond to treatment of any kind and, thus, a more robust approach, particularly with the goal of developing a new therapy for sickle cell disease, must consider natural genomic variation. Natalia and her team are looking into the development of a novel therapy for sickle cell disease that

NATALIA'S TOP TIPS FOR STUDENTS

01 Your career pathway will be challenging at times but see these challenges as an opportunity to grow and overcoming them will be easier. Remember: failures are learning moments!

02 Try to be yourself, at all times. Your perspective on things is unique to you and that can be extremely beneficial to your critical thinking skills.

03 Look out for – and actively pursue – any opportunities to get involved in research from an early stage of your career. It will always help your future.

DR NATALIA RIVERA-TORRES

Research Scientist, Gene Editing Institute, ChristianaCare
Delaware
USA.

FIELD OF RESEARCH

Gene Editing

RESEARCH PROJECT

Natalia is developing a platform for predicting gene editing outcomes in diverse patient populations with sickle cell anaemia.

FUNDERS

National Institutes of Health (P20-GM109021)
The B+ Foundation ('Be Positive')

will set the foundation for understanding the importance of genetic diversity in the development of many genetic treatments.

HAVE THERE BEEN ANY SUCCESSES SO FAR?

Yes! The first and most unique step in Natalia's research is the preparation of cell-free extracts from healthy donors or sickle cell patients. "By making these extracts, I can test each individual's response to gene editing outside of the cells," says Natalia. "Being able to produce cell-free extracts from blood stem cells to test gene editing outside of a cell, with similar outcomes to ones observed inside the cell, is a significant step forward."

HOW COULD NATALIA'S RESEARCH IMPACT LIVES?

Predicting and understanding patient population genetic variations on gene editing outcomes will lead to better and more precise universal treatments. Ultimately, this could lead to substantial improvements in the health and quality of life for sickle cell patients, as edited cells have been found to produce normal, functioning haemoglobin. Achieving this is at the forefront of alleviating patient distress, so the outlook is good.

WHAT MAKES THE GENE EDITING INSTITUTE'S LAB AN EXCITING PLACE TO WORK?

One of the aims of the lab is to get high school and college students involved in tackling sickle cell disease. There is a culture of inclusion, aspiration and producing a real sense of community in the lab – from the founder and director, through to the research scientists and assistants. By encouraging young students to get involved, producing the next generation of gene editors and researchers is made easier. "In my experience, students have been curious with all sorts of questions from what are the capabilities of the science behind CRISPR gene editing to what life is like as a scientist – it's not every day that they get to talk to a real-life scientist who they can relate to and ask anything they want," explains Natalia.

"They are interested in learning more about the science when we can give them real-life examples of how people they might know can benefit from it."

Dr Rivera-Torres showing gene edited yeast cells.

HOW DID NATALIA BECOME A GENE EDITOR?

WHAT WERE YOUR INTERESTS AS A CHILD?

As a child, I was heavily involved in music and the performing arts to the extent that I contemplated becoming an opera singer! But I was also very intrigued in science and biology, which maybe started when my parents got me a red microscope for my 7th birthday. As I grew older, the more fascinated I became with the new discoveries in biology and music became more of a hobby.

WHO OR WHAT INSPIRED YOU TO BECOME A SCIENTIST?

I was exposed to science from a young age through my father who is a physiologist and had a research lab of his own. As a kid, I would spend time in his lab, wanting to play and experiment with all the interesting things in there. I became fascinated by the concept of experimentation to find results to questions and it opened the door of understanding that there was an infinite number of things that we had no answers to, and that it was through science that those answers would be found. As I grew older, and the more I learned biology in school, the more molecular biology and genetics appealed to me.

WHAT ATTRIBUTES HAVE MADE YOU A SUCCESSFUL SCIENTIST?

I am a hard worker who is passionate about the projects I take on – I like to see them completed, regardless how challenging they might be. I am not afraid to learn new techniques and am aware I do not know everything; I recognise what I am not so good at and am open to asking for help and collaborating with people who are better in those areas. I also consider myself humble and approachable to those around me who might need assistance.

WHAT ARE YOUR PROUDEST CAREER ACHIEVEMENTS?

The day I successfully defended my PhD thesis – that was a major life accomplishment! Publishing my first paper as a first author was also a highlight.

HOW TO BECOME A GENE EDITOR

- The Genetics Society of America is the professional membership organisation for scientific researchers and educators in genetics and an important resource for those interested: **https://genetics-gsa.org/**
- CRISPR/Cas9 is a specific, efficient and versatile gene-editing technology. Put simply, it is advancing the field and is therefore essential reading: **http://www.crisprtx.com/gene-editing/crispr-cas9**
- The average salary can range anywhere between $24,000 and $80,000, depending on the level of experience: **https://nationalcareers.service.gov.uk/job-profiles/geneticist**

PATHWAY FROM SCHOOL TO GENE EDITING

Natalia says that while there are multiple routes into gene editing, some subjects you might want to consider taking are biology, genetics, molecular and cellular biology, molecule genetics and biochemistry.

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

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

Dr Rivera-Torres and Kristen Pisarcik presenting the outreach programme of the Gene Editing Institute at a ChristianaCare gala. Dr Rivera-Torres and Kristen Pisarcik presenting the outreach programme of the Gene Editing Institute at a ChristianaCare gala.

PROFILE: ERIC KMIEC, PH.D.

Dr Eric Kmiec is the founder and director of ChristianaCare's Gene Editing Institute. His research centres on understanding the process of gene repair and gene editing with a focus on CRISPR-directed genome engineering in human cells.

I grew up in a very blue-collar town and neighbourhood and neither of my parents went to college. I am most proud of that because it taught me to work hard and to never forget my roots.

As a student, I was pretty good. My best subjects were probably biology and American history. I was a fanatical butterfly catcher, capturing them, mounting them in small frames and providing them as gifts at Christmas.

My father was insistent that I focus hard on my studies and so I think he was my first inspiration. He worked at Monsanto in the pilot plant without ever earning a college degree. Kathy Dorey, Ph.D., at Southern Illinois University stands out as someone who showed me what an academic life could be like.

There is no question that relentless dedication, intense hard work and never giving up on your ideas and dreams is at the centre of success. But, it is equally important to recognise when you are chasing a hallucination – self-reflection is gained through lifelong learning and experience and being observational rationale and truthful about yourself.

I have been able to craft innovative ideas on how genes could be repaired in mammalian cells. This was the result of attaining and using a strong background in the molecular biology of recombination and repair processes, and understanding the cellular mechanisms that repair DNA.

It was very tough in the early years of gene editing as most workers in the field of gene therapy did not believe gene editing or gene correction would ever work. There were only a handful of scientists in the field and the potential of our work with not taken very seriously. I am proud that we kept going, fought uphill and sustained our ideas, despite a lot of early criticism that we were not only wrong but fanciful.

The CRISPR tool has allowed us to increase the frequency with which we repair genes and increase the precision with which we disable them. While none of the basic reactions of gene editing are new, and some parameters we identified ourselves years ago, CRISPR allowed us to pinpoint where we want to make these changes in a much more precise and efficient fashion.

It was a big moment when we were first able to use synthetic single-stranded DNA templates to correct the point mutation in a mammalian cell. These are experiments conducted in a model system in which the cell was colourless until the targeted gene was corrected, and then it turned green.

In those early days, there were probably only two cells out of a thousand that were green, but they grew and expanded, and we were thrilled to see them appear. When my graduate student, Brett Sansbury, Ph.D., developed the system and was able to do gene editing on a chip, it was fantastic and something I had always dreamed of.

Now is the most exciting time to be a geneticist and for young people to choose to study gene editing. With the molecular toolbox created by our generation, and the imagination and computational skill set of our younger generations, the possibilities are simply endless. Excellent technological developments, with a serious dose of humanity and ethics, is what the next generation will have to deal with, but I am confident they will do so intelligently.

PROFILE: KRISTEN PISARCIK

Kristen Pisarcik is a research assistant and science educator at ChristianaCare's Gene Editing Institute.

As a child, science and photography were my primary interests. I have always enjoyed biology, specifically marine biology, astronomy, and archaeology. I was also interested in anything art-related but enjoyed photography and knitting the most.

I remember I got my hands on a book about all the different kinds of dolphins and whales in the world and, from that moment on, I knew I was going to do some sort of biology. Most of my inspiration came from reading books that contained as much information as I could digest.

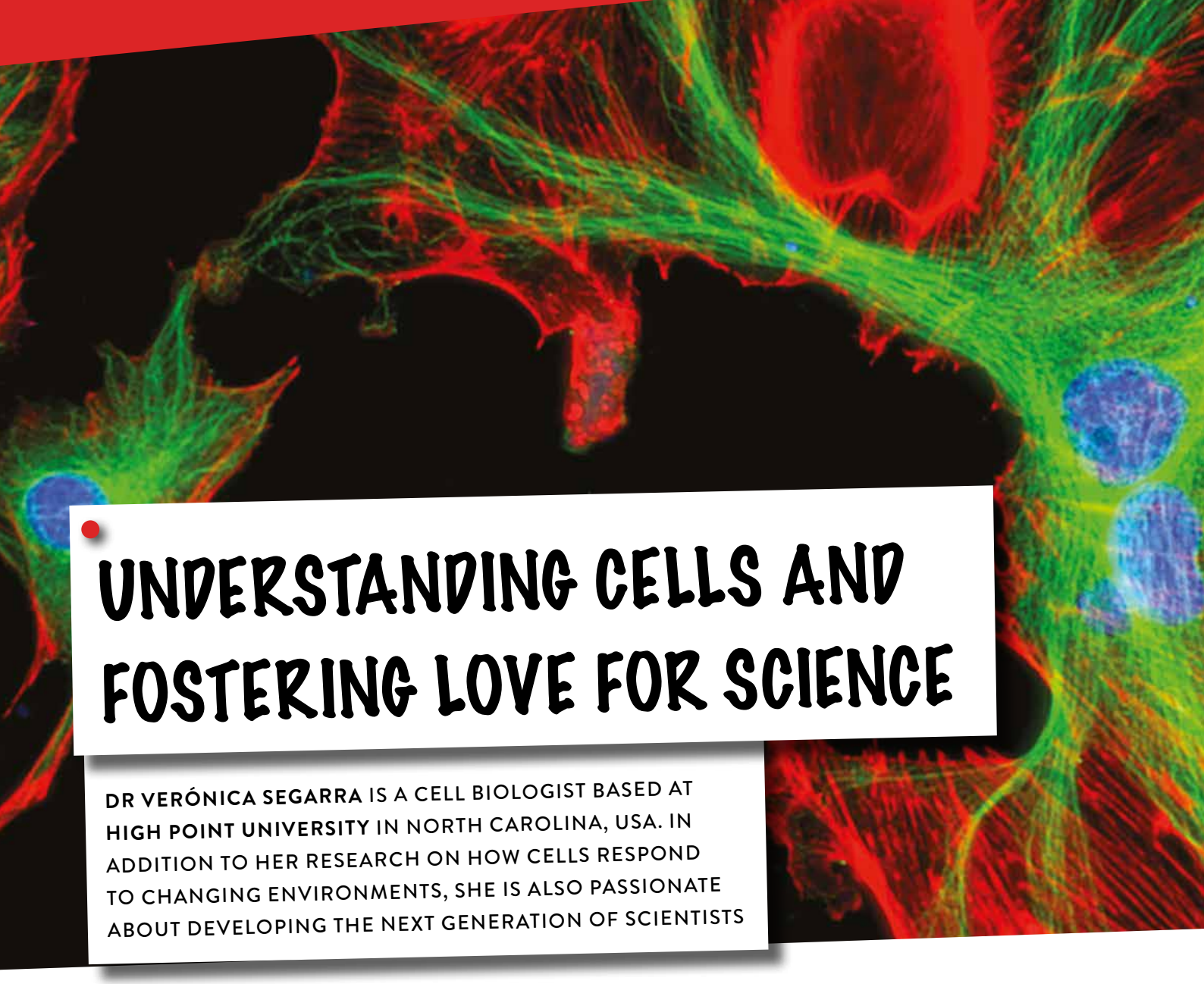
I started working at the Gene Editing Institute as a student at Delaware Technical Community College doing undergraduate research. After graduation with my associate degree, I continued to work with them on a grant. Currently, I am pursuing my bachelor's degree, with hopes to complete my master's and maybe a doctorate.

My role is to listen in to all the research being done in the lab and then think about ways that this high-level science could be converted into curriculum for students at any level. This includes materials as well as potential laboratory exercises.

The most challenging and rewarding part of this is definitely taking the complicated science and making it understandable and accessible to students and the general public.

My role requires collaboration on every level. I am commonly talking to students, to teachers (at all levels), or to foundations/companies/organisations. I have learned that this role is based on the collaboration and feedback of others.

I have many ambitions for the future. I hope to reach as many students, in as many backgrounds, with as many levels of education as possible, to talk about gene editing and science in general. If I can spark an interest in science in any student, I will be happy. I also hope to be able to work on a gene editing project that leads to a cure or therapy for a disease – I think that would be something really cool to contribute to!



UNDERSTANDING CELLS AND FOSTERING LOVE FOR SCIENCE

DR VERÓNICA SEGARRA IS A CELL BIOLOGIST BASED AT **HIGH POINT UNIVERSITY** IN NORTH CAROLINA, USA. IN ADDITION TO HER RESEARCH ON HOW CELLS RESPOND TO CHANGING ENVIRONMENTS, SHE IS ALSO PASSIONATE ABOUT DEVELOPING THE NEXT GENERATION OF SCIENTISTS

Cells are the basic unit of life and perform a vast array of functions in the human body, ranging from providing structure and support to facilitating growth, producing energy, and aiding reproduction. Recent estimates put the number of cells in a single human body at around 30 trillion (yes, that means 30,000,000,000,000), with more than 200 types of cells performing different specialised jobs. In spite of this incredible diversity, there are many important traits and abilities that all cells have in common. It is hardly surprising, then, that scientists around the world dedicate their lives to studying more simple, single-celled organisms to enhance our understanding of cellular function and how they are able to do the wonderful things they do.

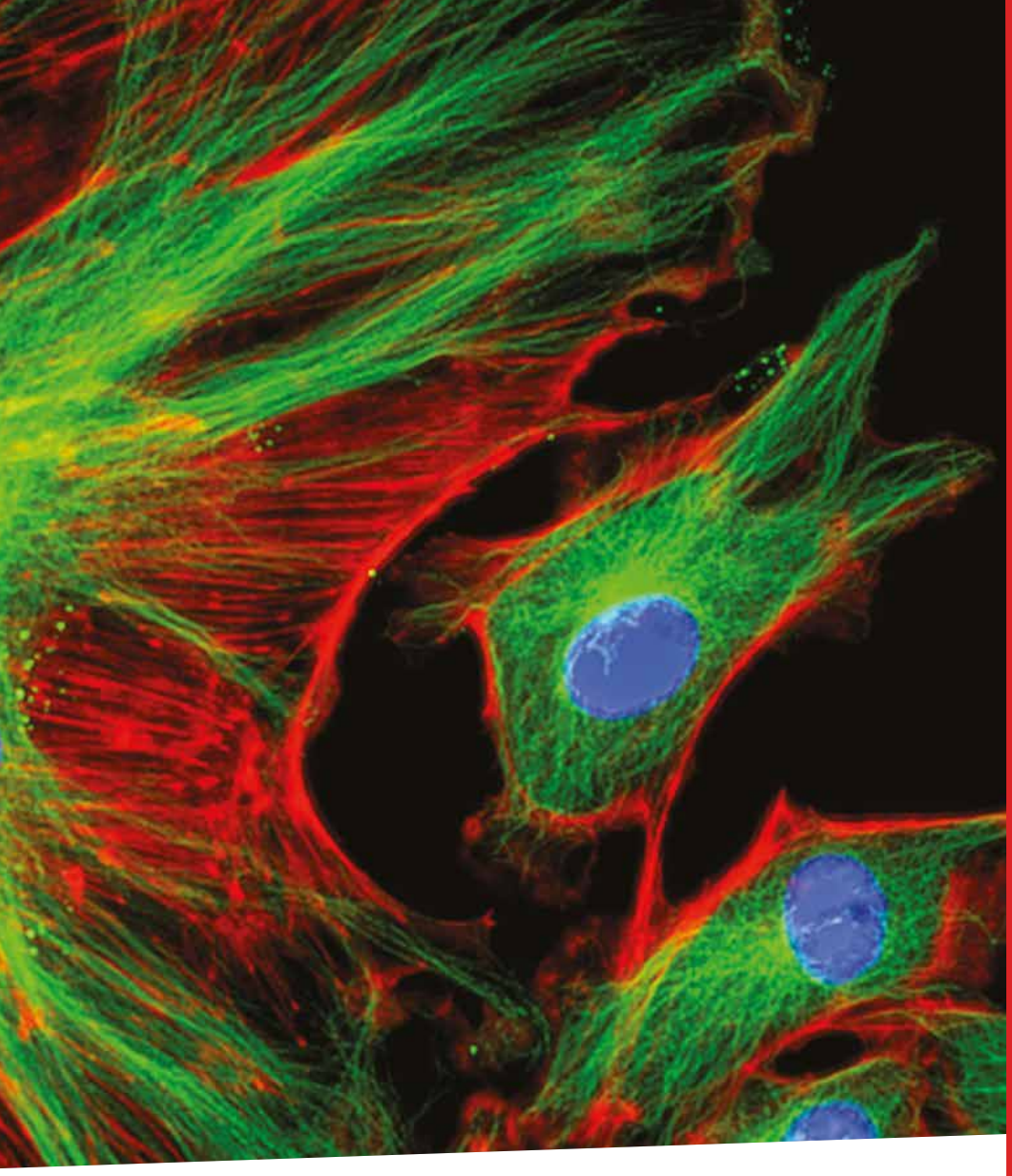
Dr Verónica Segarra is one such scientist. Based at High Point University in North Carolina, USA, Verónica is a cell biologist who seeks to understand more about the membrane trafficking events that enable the cell to adapt to conditions of stress and starvation. Put simply, stressed cells must re-organise their membranes and transport damaged materials between different cellular compartments to recycle them and regenerate valuable resources. This carefully orchestrated movement of materials throughout the cell is known as membrane trafficking, and is especially critical to survival in times of cellular stress, such as starvation.

HOW IS VERÓNICA USING BAKER'S YEAST IN HER STUDIES?

Scientists often study cellular biology using baker's yeast, since this simple, single-celled organism shares many of the same behaviours found in human cells, but is easy to grow using cheap ingredients. Verónica's team uses baker's yeast to study how cells in general respond to stress by engaging in a behaviour called autophagy, or cellular self-eating. This process cleans out damaged organelles and recycles unnecessary cellular components, freeing up resources that are critical to the cell's survival in times of stress. "We follow how stress triggers cells to mobilise specific autophagy-related proteins and transport them on different journeys throughout the cell," explains Verónica. "We are able to follow the movement of these proteins in live cells by genetically modifying these cells so that the key proteins will glow with green or red fluorescence." By using microscopes to follow these movements, the team is able to understand the role of each autophagy-related protein in making the process successful.

WHAT HAVE BEEN SOME OF THE KEY FINDINGS?

Biologists have long known that cells can be divided into compartments such as the nucleus, vacuole and endoplasmic reticulum, each with its own unique function. Each autophagy-related protein can be found in multiple different compartments. However, starvation can set them into motion, summoning them to travel to a new compartment, where they work together to activate recycling to facilitate cell survival. Remarkably, the team has discovered that autophagy-related proteins contain small tags that act like molecular mailing addresses, instructing the cell to deliver them to a specific compartment. Much like when somebody sends a letter and the address explains where it needs to go, these proteins contain a signal



DR VERÓNICA SEGARRA

Assistant Professor of Biology, High Point University, North Carolina, USA

FIELD OF RESEARCH

Cell Biology

RESEARCH PROJECT

Verónica studies how cells control the movement of molecules inside them. The findings could lead to the development of improved treatments for a range of diseases.

FUNDERS

National Institutes of Health, National Science Foundation

Verónica's ACCESS work is supported by the National Science Foundation (NSF) grant number 1744098. Her Accomplishing Career Transitions (ACT) work is supported by an Innovative Programs to Enhance Research Training (IPERT) grant from the National Institute of General Medical Sciences (NIGMS; award number 2R25GM116707).

that helps the cell to place them where they are needed the most. "This finding has shed light on how the ability of a cell to adapt to stress relies upon many different proteins reaching the correct cellular location and then working together for cell survival," says Verónica. "In this way, we are learning how the placement of each protein within the cell facilitates its function."

WHAT ARE THE NEXT STEPS FOR THE RESEARCH?

We now know that baker's yeast and other cells use autophagy to survive starvation. But do they also use autophagy as a strategy to survive many other types of stress? For instance, Verónica's group has uncovered evidence that yeast cells might use autophagy to survive the stress of freezing temperatures. "While there is some evidence that autophagy contributes to cells surviving this kind of freeze-thaw stress, it has not been directly tested yet. The answer to this question has implications for the baking industry and other biotechnology businesses that might benefit from genetically enhanced strains of baker's yeast with increased resistance to freezing," says Verónica. "Also, because baker's yeast cells are very similar to human cells, this knowledge can provide us with clues about how to better preserve human cellular material for medical research and therapeutic purposes."

HOW DOES VERÓNICA THINK YOUNG PEOPLE CAN BE ENGAGED IN SCIENCE?

Alongside her work as a cell biologist, Verónica is passionate about helping the next generation of students become interested in science. She and her team have researched new ways to engage students and facilitate their learning in science. "In my experience, students are engaged when they feel that they belong in science, that they are needed and appreciated in their fields of interest. Students feel like they belong when we give them space and the resources to develop their unique talents as scientists," says Verónica. "Engaging young scientists in individualised ways will provide us with future professionals who approach science from an angle that is innovative and different from everyone else's. Only then will we be able to realise the full potential of our talents and respond to the current challenges that affect our society today."

IN WHAT WAYS CAN THE ARTS HELP YOUNG PEOPLE STUDYING STEM SUBJECTS?

The arts and sciences are surprisingly complementary. Making scientific discoveries requires creativity and the ability to think 'outside the box'. The arts can help students flex those creative muscles and practise finding new and interesting ways to approach problems. This flexible thinking is crucial for scientists trying to find solutions to new challenges, especially when these challenges are unprecedented. It is important that we all recognise that being a 'scientist' means so many different things – there are an extraordinary number of careers in STEM, including ones deeply connected with art, such as careers in medical or molecular illustration.

VERÓNICA'S WORK WITH SCIENTIFIC SOCIETIES

Verónica believes that another way to develop the next generation of scientists is through membership in scientific societies. "Professional societies are communities of scientists that share a particular interest in a field such as microbiology or biophysics. These are organisations that can expose you to cutting-edge research and help you connect with mentors, advisors and future colleagues," explains Verónica. "They can also help an aspiring scientist acquire strategies to become an independent scientist in a particular field."

Importantly, these organisations often have a range of ways to engage aspiring scientists and develop their talents in science. There are usually membership levels and programmes that enable students to learn more about a given scientific field and form connections with other members.

Verónica belongs to a number of scientific societies, including the American Society for Cell Biology (ASCB). As a member of ASCB, she has established working relationships with other members who have helped her become a better scientist and take on leadership and mentorship roles in the field.

WHAT IS REWARDING ABOUT VERÓNICA'S WORK WITH THE AMERICAN SOCIETY FOR CELL BIOLOGY (ASCB)?

"Being part of ASCB enables me to stay connected with young scientists that are up and coming in the field and they constantly inspire me," says Verónica. "Of course, my work also enables me to stay connected with more seasoned scientists in my field who can provide help and guidance when needed."

As part of her work with ASCB, Verónica is leading its Accomplishing Career Transitions (ACT) programme. The programme enables cell biologists who are starting out their independent careers to customise and individualise their professional development and training through a longitudinal mentoring framework. The ultimate aim is to facilitate their successful transition into the academic STEM workforce. Verónica is keen to emphasise that many of the transferable skills that scientists will need throughout their career are not actually taught through formal training. Thus, Verónica works to design innovative programmes that fill this gap and help young scientists learn these transferrable skills and put them into practice.

WHERE DOES VERÓNICA'S PASSION COME FROM AND WHAT MOTIVATES HER?

"I think the energy and drive to move forward and make progress comes from an overlap between my professional and personal missions and values. For example, helping others speaks to the values with which I was raised and is therefore an important part of my identity," says Verónica. "My goal of helping others move forward in their quest of becoming successful scientists aligns perfectly with my personal mission – I am strongly motivated to support the next generation the same way I was helped by my teachers and mentors during my time as a student."

If all that was not enough, Verónica also cofounded The Alliance to Catalyze Change for Equity in STEM Success (ACCESS), which brings together diversity-focused committees from five different scientific societies. When Verónica was the co-chair of the diversity-focused committee of the ASCB (called the Minorities Affairs Committee), she identified a need and looked for ways to collaborate with others to satisfy it.

HOW TO BECOME A CELL BIOLOGIST

- The American Society for Cell Biology is an exhaustive resource that provides a wealth of information on the international community of biologists: **https://www.ascb.org/**
- National Geographic has a brilliant resource library, which includes an entire section dedicated to cell biology. We cannot recommend this resource enough: **https://www.nationalgeographic.org/topics/resource-library-cell-biology/?q=&page=1&per_page=25**
- The average salary can range anywhere between $81,150 (microbiologists) and $105,940 (biochemists and biophysicists), depending on the level of experience.

PATHWAY FROM SCHOOL TO CELL BIOLOGY

Verónica believes that biology, chemistry and physics are good subjects for aspiring cell biologists to take while at school. "Aspiring scientists should also take any other courses they enjoy, especially ones that will inspire them to create and formulate creative solutions to challenges we face as a society," says Verónica. "Problem solving and thinking creatively are transferable skills that can be applied in any field of knowledge."

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

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

HOW DID VERÓNICA BECOME A CELL BIOLOGIST?

WHAT INTERESTS DID YOU HAVE AS A CHILD?

So many! I loved the arts, including painting and music (I play the clarinet). I also loved reading and writing, as well as playing and exploring!

WHO OR WHAT HAS INSPIRED YOU IN YOUR CAREER?

I had an inspiring science teacher early in school and she made me want to become a scientist. I never doubted I would become one, even when the going got tough – as it often does when you are doing something worthwhile. I have had many mentors along the way who have been a big help, including more experienced scientists, but also peer mentors who have been at a similar stage in their careers.

WHAT CHARACTERISTICS HAVE ENABLED YOU TO BE A SUCCESSFUL SCIENTIST?

I have worked hard through challenges in ways that speak to who I am as a person and my values. I do this despite any fear of failure I might experience. When I make mistakes, I find ways to learn from them and use these lessons to be better in the future.

WHAT HAVE BEEN YOUR PROUDEST CAREER ACHIEVEMENTS SO FAR?

I am proud that I have accomplished my goal of becoming a scientist – looking back and reflecting on my journey makes me super happy. Something that I have come to value even more than my own career trajectory is the accomplishments of my students. I have had the honour of mentoring many undergraduate scientists and have watched each of them create a unique professional trajectory. I am so proud of them!

WHAT AMBITIONS DO YOU STILL HAVE TO ACHIEVE?

My ambitions are to stay relevant and needed in whatever it is that I am doing. I find that my long-term goals tend to change over time, as I adapt and reflect on my life experiences in science and beyond. I find that very exciting – the possibilities are endless in that I can still become whatever it is I want to become. One of my main goals is to stay engaged and creative, building opportunities for myself and others that enable us to connect with science in authentic ways.

VERÓNICA'S TOP TIPS

01 Do science in a way that speaks to who you are as an individual. Try and create a unique niche that speaks to your passions and values!

02 Do some research on professional societies at the start of your career. Becoming part of the community from the outset will stand you in good stead for the future and undoubtedly introduce you to like-minded people who can inspire you to achieve greater things. Fact: failing fast is the best! Then you can regroup and try again.

Verónica and her undergraduate research team attend the annual meeting of the Association of Southeastern Biologists in 2016 to present their work.

Verónica and her undergraduate research students, excited to begin the 2016 Summer Research Program in the Sciences at High Point University.

Verónica and her undergraduate research students examine a Petri dish containing live budding yeast.

HOW CAN STEM EDUCATION PROVIDE 'LIGHT-BULB' MOMENTS?

DR LIZ JOHNSON IS A STEM EDUCATION SPECIALIST BASED AT **SOUTHERN RESEARCH** IN ALABAMA, USA. SHE IMPLEMENTS AN OUTREACH PROGRAMME THAT WORKS TO ENHANCE 6TH-12TH GRADE STEM EDUCATION AND INSPIRE YOUNG PEOPLE TO EMBRACE THE JOY OF ALL THINGS STEM

The importance of science, technology, engineering and mathematics (STEM) can hardly be overstated. These areas of research affect our everyday lives in numerous ways, from the smartphones we have, to the houses we live in, from the energy we use, to the medicine we benefit from; none would be possible without STEM. It is vital that teachers and mentors across the world encourage active student participation in STEM – something that Dr Liz Johnson is passionate about.

Based at Southern Research in Alabama, USA, Liz is a STEM education specialist who, along with her colleague Dr Kathryn Lanier, devises STEM outreach activities such as summer learning programmes, field trips, after-school programming and science fairs. The programme targets 6th-12th grade students (11-18 year olds).

ARE THERE SIMILARITIES AND DIFFERENCES BETWEEN THE DIFFERENT AGE GROUPS?

Liz and the team want to expose students to the wonders and excitement of STEM and strengthen their confidence in pursuing STEM careers. They do this by engaging them in activities that will be increasingly relevant as the world becomes ever more STEM-centric. Although the ultimate aim of the programme is the same for all ages, there are differences between middle and high school students. "The STEM content of each programme is designed to align with the standards and curriculum of the participating age groups. For example, in our green engineering field trip series, we use calculus with high school students and algebra with middle school students," explains Liz. "A major similarity between the age groups is their level of excitement when entering our STEM Lab – it looks quite different to a typical school lab. When students enter, they tell us it looks like Disney World or Nickelodeon studios!"

WHAT KIND OF FIELD TRIP EXPERIENCES ARE PART OF THE PROGRAMME?

Southern Research designs field trips linked to its key research areas of Drug Discovery, Drug Development, Engineering, and Energy & Environment. For example, through the green engineering series, students explore renewable energy and are challenged to design the most energy efficient wind turbine or solar panel prototype.

Liz describes another field trip focused on the spread of infectious diseases: "Students participate in a simulated disease outbreak and are tasked with collecting data to determine patient zero, while also considering the factors that led to the outbreak. They learn about the primary and secondary immune response and how it relates to vaccines for diseases, and they diagnose disease in patients using enzyme-linked immunosorbent assays (ELISAs)."

HOW DOES THE PROGRAMME HELP STUDENTS TO THINK CRITICALLY AND PROBLEM SOLVE?

A key part of the programme is presenting students with real world problems that need solutions. Relevant background materials and resources are provided but, Liz explains, "Students are challenged to drive the design of the experiment themselves." Collaboration is achieved by having the students work in teams and, quite often, their first efforts are unsuccessful – this requires them to analyse their approach, reassess their strategy and try again.

WHAT DOES LIZ AIM TO ACHIEVE WHEN SHE VISITS A SCHOOL?

Liz and the team put on STEM shows which involve large-scale experiments designed to engage and inspire students. "Through these experiences, we hope to capture students' attention and encourage them to participate in STEM courses and extra-curricular STEM activities," says Liz. "We also aim to reinforce the concepts students are learning in their lessons through memorable and exhilarating demonstrations."

WHAT HAVE BEEN HIGHLIGHTS OF THE SUMMER ACADEMIES?

"Last year, we offered a new week-long programme called Drone Academy that introduced high school students to computer aided design (CAD), 3D printing, electrical engineering, and drone technology," enthuses Liz. "A major highlight of this programme was seeing the wide array of creative drone designs students developed in a matter of days, with little to no 3D modelling experience. We had drones that looked like UFOs, the Millennium Falcon from Star Wars, and one that even incorporated chicken feet as landing gear! We also had a special guest, Dr Chris Crawford from the University of Alabama, who shared his research on brain-computer interfaces (BCI) and showed students how to pilot a drone using their brain waves and an electroencephalogram (EEG) sensor!"

As with everything Liz and the team at Southern Research devise, such programmes are about instilling a long-term love of STEM. She adds, "The Drone Academy led some students to pursue internship opportunities, as well as enrol in pilot licence programmes."

The opportunities offered by Southern Research are wide and varied because, as Liz knows, that is the joy of STEM itself.

MEET THREE STUDENT STEM AMBASSADORS

ALEXANDRA AUDIE
University of Alabama at Birmingham
Majoring in Biomedical Sciences
Minoring in STEM Education

As a high school senior, I was Vice President for the Girls Exploring Math & Science programme when we presented at the 2019 exposition at Southern Research. I thought it would be amazing to work there. Six months later, I listened to a lecture given by Dr Kathryn Lanier who spoke about openings for STEM ambassadors. A month later, I started as an ambassador!

I assist with stimulating lab experiences for a variety of STEM branches, mentoring students to discover their passions, and having conversations to probe students' interests and understanding. My role involves influencing somebody else's future and that's priceless.

I have gained confidence in my ability to lead others, which has led to my growth as a student and an employee. I have been exposed to new situations and opportunities. Most importantly, I have gotten affirmation that I am doing what I love.

Ultimately, I aim to obtain my Masters in Physician Assistant Studies so I can become a neonatal physician assistant. I would like to practise neonatal medicine and actively participate in diagnostic and neonatal treatment research.

I would tell students considering a future in STEM to find what they are passionate about. Remember, it does not matter what other people think. When you find what you are passionate about, you won't want to settle for anything else.

AMBER LAKEY
University of Alabama at Birmingham
Majoring in Mathematics
Minoring in STEM Education

I heard about the programme when the STEM Education Outreach Director, Dr Kathryn Lanier, visited a class I attended. She gave a presentation and I fell in love with the programme instantly. I applied, interviewed and was offered the position.

I work with individual students as well as groups. As students experience the lab, I ask critical thinking questions, guide their thought process, and provide instructions for the experiments.

I love that STEM is a collection of separate disciplines that aren't really separate at all! If you study one STEM field, you get to study them all – STEM subjects all rely on each other to work. Being involved in STEM means you're involved in something much bigger and more important than you think.

Working at Southern Research is incredibly rewarding and fun. I get to tell a new group of students how awesome STEM is every time I work! My passion is education and the lab is the perfect place to encourage learning in a way that makes students excited.

I plan on teaching maths at high school level before moving on to school administration. My dream is to run for office and influence educational policy in a way that encourages schools to be more open with students about opportunities and options.

If you are considering studying in STEM, don't ever think that you're done learning. STEM is so exciting; there will always be something new to learn and discoveries to be made!

DR LIZ JOHNSON

STEM Education Specialist, Southern Research, Birmingham, Alabama, USA.

FIELD OF RESEARCH

STEM Education

RESEARCH PROJECT

Liz is part of Southern Research's STEM Education Outreach programme, which enhances 6th-12th grade STEM education by drawing upon the expertise and scholarly contributions of the Southern Research community.

FUNDERS

The State of Alabama, The Community Foundation of Greater Birmingham, American Honda Foundation, Motorola Solutions Foundation, Best Buy, Wells Fargo, Spire Energy.

Dr Liz Johnson teaching students about the properties of liquid nitrogen.

TYHRE HEATH
University of Alabama at Birmingham
Majoring in Mathematics
Minoring in STEM Education

I was contacted about being a STEM ambassador by UAB Teach, a university programme that helps prepare students to become highly qualified STEM educators. Once I researched what a STEM ambassador actually was, I was eager to get started! It is an amazing programme.

As STEM ambassadors, we work with and guide students through different experiments and lessons. Our ultimate purpose is to make them comfortable enough to use their own critical thinking skills to succeed. Primarily, I like mathematics, but I think STEM prepares you for all real-world applications.

From working on this programme, I have gained more confidence working with middle school aged children, knowledge about science subjects I wasn't familiar with, and a 'family', with Dr Lanier, Dr Johnson and fellow ambassadors. We are encouraged to do well in the programme, to do better in school and to be career ready!

When I graduate, I hope to work in one of the school systems I have seen come through the STEM lab, so I can continue to work closely with Southern Research. As an upcoming teacher, I aim to change students' minds about math – I plan to make maths as enjoyable as possible!

STEM can take you anywhere. If you're not sure if STEM is for you, join a programme like Southern Research's so you can actually see what it's like to be in the field.

HOW TO BECOME A STEM EDUCATOR

• Teach.com has an entire section of its site dedicated to helping students realise their ambitions of teaching STEM: https://teach.com/careers/become-a-teacher/what-can-i-teach/stem/

• STEM Learning is a UK-based enterprise that has a wealth of information regarding achieving a leading STEM education for young people. Wherever you are based, it will give you important context if you are considering a career as a STEM educator: https://www.stem.org.uk/about-us

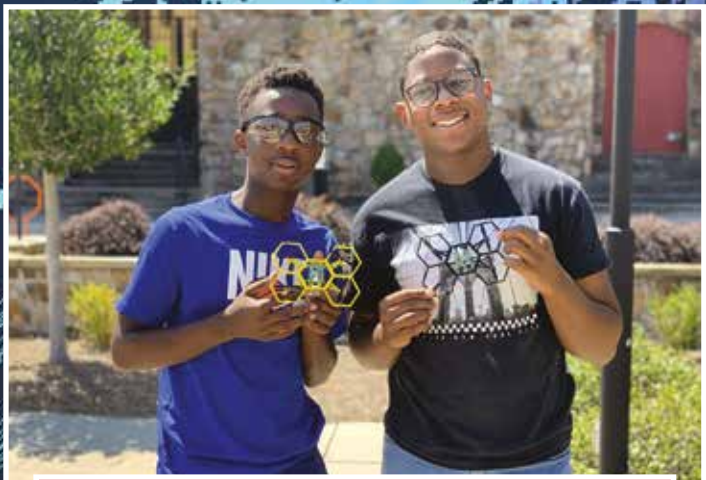
• 100Kin10 is a wonderful organisation with a mission to enrich America's classrooms. The chief aim is to get 100,000 excellent STEM teachers into classrooms by 2021: **https://100kin10.org/**

PATHWAY FROM SCHOOL TO STEM EDUCATION

Any number of STEM courses, including chemistry, biology, physics, geology, computer science, engineering and mathematics, can pave the way for a career in STEM education but Liz insists the most important thing is to choose courses you are passionate about. "That passion will not only make the course more enjoyable, it will also make your presentation of the topic more engaging to your audience," explains Liz. "I would also recommend you take a few classes in education if you are able. This can help you develop the techniques and tools to effectively implement STEM activities both in and out of the classroom."

Keep in mind that you do not have to become a scientist or engineer if you study STEM. The beauty of these subjects is that they are integrative and help us make informed, data-driven decisions to solve global issues. "Students with a background in STEM can go on to become financial advisors, data analysts for Disney World, virtual reality game developers, public health officials, project managers for social media organisations, or even CEOs of fortune 500 companies," says Liz

Southern Research STEM Education Specialist, Liz Johnson, works with a student from Tarrant High School.



Josh Hill, left, and Caleel Holifield, both freshmen at Jefferson County International Baccalaureate School, show off the drones they built at Southern Research's Drone Academy.

HOW DID DR LIZ JOHNSON BECOME A STEM EDUCATOR?

WHAT WERE YOUR INTERESTS AS A CHILD?

I was a budding ecologist. I loved being outdoors and discovering all the wildlife that lived in the surrounding areas. I often tried to bring creatures home as pets – thankfully, my mother reminded me of the importance of leaving them in their natural habitat! I was also an avid swimmer and spent most of my free time in the water, both competitively and for fun.

WHO OR WHAT HAS INSPIRED YOU IN YOUR CAREER?

I didn't realise I wanted to pursue STEM as a career until I was a senior at the University of Alabama and participated in undergraduate research with Dr Ryan Earley. In his lab, I fell in love with the excitement and freedom of pursuing scientific questions that no one knew the answers to and I loved the collaborative environment. Through my dissertation work with Ryan, I discovered a passion for mentoring undergraduates in the scientific process. Watching students progress from timid lab assistants to individuals designing and driving their own research projects lit a fire within me to pursue STEM education. I wanted to continue to make a positive impact on future generations through engaging students in hands-on, experiential STEM learning and give them the opportunity to experience the addictive 'light bulb moment' when a new idea or concept clicks!

WHAT ATTRIBUTES HAVE ENABLED YOU TO BECOME A SUCCESSFUL SCIENTIST?

Failure, tenacity and collaboration. Whether an experiment doesn't pan out or a grant is denied, failure is an all too common occurrence in the scientific world. Rather than seeing those failures as dead ends, I learned to embrace them as opportunities to try new research techniques or re-evaluate research proposals. When I felt discouraged, I reached out to my lab mates and mentors, and we worked together to develop new ideas, or they offered different perspectives that helped improve my work. These attributes continue to help me be successful in my career in STEM education.

HOW DO YOU OVERCOME OBSTACLES IN YOUR WORK?

I am a strong believer in 'teamwork makes the dreamwork', so I will often seek advice and input from my co-workers, family, or friends. Often, they have come across similar challenges and can provide valuable insights. I have found it very helpful to get together with a group to bounce ideas and solutions around. Two brains are better than one!

WHAT ARE YOUR AMBITIONS?

My ultimate career goal is to help develop and improve scientific literacy among K-12 students. While not every student will pursue a career in STEM, the critical thinking and problem-solving skills they learn in STEM courses will help them succeed at school and in their career, and it will help them understand and make informed decisions about many of the issues society faces, like climate change, vaccine development, and genetically modified foods.

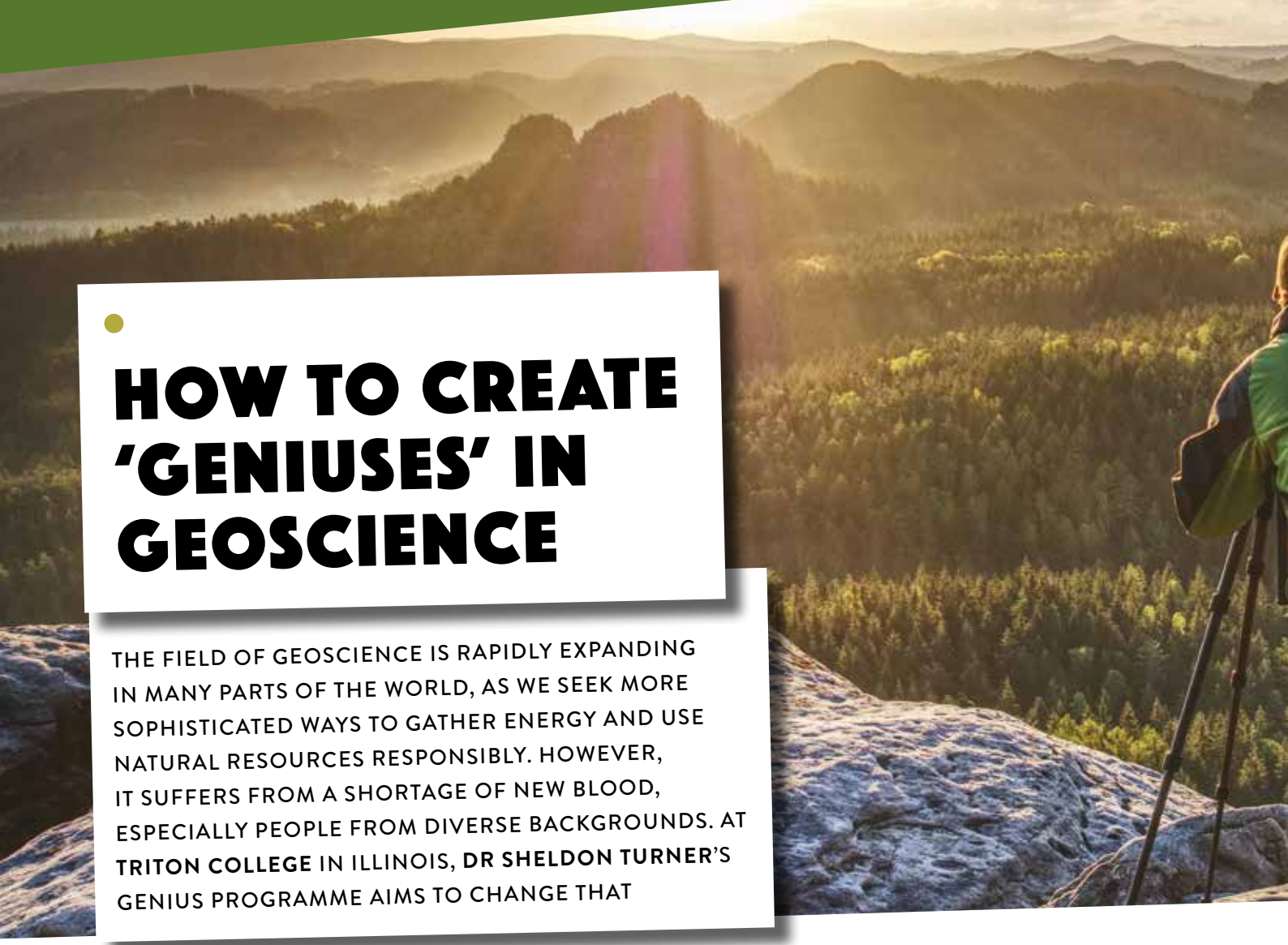
LIZ'S TOP TIPS

1. Say yes to almost every opportunity. The best way to figure out what interests you or what you're passionate about is to give it a try. Trying different things can also help illuminate what you don't like. So, join the robotics team, take the elective class on marine biology, participate in a creek clean up, or volunteer at a local hospital!

2. Don't be discouraged by failure. Utilise these opportunities to identify and improve weaknesses in your experimental design or understanding of a topic. If you feel stuck, don't be afraid to ask for help.

3. Start maintaining a healthy work-life balance from the outset. It can be very easy to put 100% of your time and effort into your work, especially when you are highly motivated and passionate about the subject. Spending time outside your job can stimulate new ideas that can improve your work and lower stress.

Dr Liz Johnson teaching students about solar energy.



HOW TO CREATE 'GENIUSES' IN GEOSCIENCE

THE FIELD OF GEOSCIENCE IS RAPIDLY EXPANDING IN MANY PARTS OF THE WORLD, AS WE SEEK MORE SOPHISTICATED WAYS TO GATHER ENERGY AND USE NATURAL RESOURCES RESPONSIBLY. HOWEVER, IT SUFFERS FROM A SHORTAGE OF NEW BLOOD, ESPECIALLY PEOPLE FROM DIVERSE BACKGROUNDS. AT **TRITON COLLEGE** IN ILLINOIS, **DR SHELDON TURNER**'S GENIUS PROGRAMME AIMS TO CHANGE THAT

Dr Sheldon Turner heads the Triton GENIUS (Geo-Engineering Innovations through Undergraduate Scholarship) Program at Triton College in Illinois, USA. He is passionate about making geoscience accessible for all. The programme provides full-ride scholarships, along with intensive mentoring, for academically gifted students from low-income backgrounds to pursue careers in geology, environmental science, engineering and related fields. There is also the opportunity for hands-on research in the field.

SEEKING SOCIAL CAPITAL

"Both geoscience and related engineering careers are seeing a fast increase in employment opportunities, while at the same time we are seeing shrinking enrolment in these areas within higher education," Sheldon explains. He says this is compounded by the lack of 'social capital' – the sense of belonging, trust and role models for students pursuing an education in an area in which they are underrepresented. Due to the lack of diversity in geoscience and STEM in general, he feels they do not accurately reflect the knowledge and needs of the communities they aim to serve.

This is especially pertinent in the state he calls home. "In Illinois, we have both rural agriculture and major urban areas right next to each other, each with their own set of environmental issues," he says. "Government bodies and private companies alike need people with the knowledge and skillsets to solve these problems."

Sheldon works with students mainly on water quality issues, but also points towards Illinois' role in the energy industry. "The state has a long history of fossil fuel production and continues to play a role in energy policy. From our electricity, to the water we drink, to the materials that build our homes and roads, Illinois' geoscientists and engineers are hidden heroes that most of the population doesn't even know exist, let alone see them as viable career role models."

TAKING TO THE WATER

Sheldon gets his students involved in tackling local issues like water pollution and flooding. "We've collaborated with civil engineers on projects dealing with the Chicago River, the most famous and populated river in the region," he says. "Next, we plan to do the same for the Des Plaines River, which flows right next to campus. Most of my students are well-acquainted with the effects of flooding, as every few years the front entrance of campus is underwater!"

Sheldon believes that students have an important role to play in collecting data about the river, and they also benefit from picking up important scientific skills along the way. "While students learn about how to collect and organise data, all important skills for new scientists, they are also making an impact on the future of their community," he explains. "Through sharing what they learn with friends and family, and creating a better awareness of our natural environment, they are making a positive impact on the future of their community."

TURNING TO WORMS

Sheldon emphasises the importance of a student-led approach in coming up with new ideas and putting them into practice. He cites a recent project: "One student had been collecting the water runoff from a worm compost bin for several years and wondered whether it could be used as fertiliser in a hydroponics system. We designed and built such a system, along with several other

DR SHELDON TURNER

Geology and Environmental Science Principal Investigator, Triton GENIUS Scholarship Program, Triton College, Illinois, USA.

FIELD OF RESEARCH

Geoscience

RESEARCH PROJECT

Making geoscience more accessible to all through the GENIUS programme and finding new innovative methods for engaging teaching.

FUNDER

National Science Foundation (NSF)

This work is/was supported by NSF, under award number 1741971. The contents are solely the responsibility of the authors and do not necessarily represent the official views of NSF.

students, and the project eventually earned an award in a collegiate science competition. I've since procured much more sophisticated hydroponics equipment and am looking forward to continuing the project once the coronavirus pandemic is over." Sheldon is rightly proud of his students' achievements – the hydroponics worm waste project saw them attending their first scientific conference and competing with students from prestigious universities – a great accolade for the GENIUS programme.

It is rare for students to be able to access experiences that involve carrying a project all the way through from an initial idea to fruition, especially within the early years of college. The GENIUS programme's ability to tap into this means that it creates scientists who are more engaged with the world around them, within the community rather than separate from it.

MENTOR METHODOLOGY

"The thing I love most about mentoring students through research rather than classroom-based learning is that it naturally becomes driven by the students' own inquiries," says Sheldon. "They learn so much more by experiencing the world directly rather than through a screen or a textbook." Sheldon keeps in touch with many ex-students once they graduate – many remain colleagues, largely due to their close collaboration and the supportive working relationships formed while carrying out research.

Sheldon believes it is important to treat students as colleagues rather than 'kids', especially given the range of ages in the community college setting. "They all have life experience and shouldn't be treated as blank slates, but rather taught to utilise the wealth of knowledge they already have."

A RECIPE FOR SUCCESS

"We've given out nearly 30 full-tuition scholarships thanks to the grant from the National Science Foundation (NSF)," says Sheldon. "We've also built some amazing partnerships with major universities such as Illinois Institute of Technology, which allow our GENIUS scholars to transfer with guaranteed scholarships."

They also reacted quickly to ensure students' welfare during the coronavirus pandemic. "When Covid-19 first came to the region, many students lost their jobs and were worried they wouldn't be able to remain in school. We worked quickly with NSF and our financial aid office to allocate extra funds to students to help with living costs, which many students have said were the reason they were able to pay rent."

Sheldon hopes the GENIUS programme will continue even after the NSF grant period ends and is working to make sure that Triton College is seen as a gateway to STEM careers. "This project is also teaching us about what works and what doesn't, so we are building a model we can share with other schools wishing to do something similar."

Sheldon's commitment to his students and to teaching geoscience is palpable. And the scholarship programme? It's genius!

ABOUT GEOSCIENCE

Geoscience covers any scientific discipline that deals with the Earth. This includes exploring the materials that are found within the Earth, how they got there, and the interplay between the planet's natural systems. Sheldon ardently believes it is a field that should be open to anyone with a passion for the subject, and he explains why.

WHY ARE YOU SO PASSIONATE ABOUT INCLUSION IN GEOSCIENCE?

All disciplines improve with improved diversity. Science's goal is to be objective, but our human experiences shape the questions we ask – and we need to ask a diverse range of questions. Geoscience is one of the least diverse STEM fields in the USA, and place-based knowledge is crucial for finding sustainable solutions. We need to empower people to understand and advocate for their own community instead of relying on outside help.

WHAT DO YOU FIND CHALLENGING ABOUT GEOSCIENCE?

I find geoscience to be a very spatial field, meaning we need to able to visualise things in three or even four dimensions. We have to be good at imagining the unseen, as lots of the things we deal with are invisible, underground, or happened a long time ago.

WHAT ARE THE MOST PRESSING ISSUES FACING GEOSCIENTISTS?

I believe the two biggest challenges for society are how to source energy without exacerbating climate change, and how to ensure our communities have reliable clean water. Geoscience has the answers for both questions, but the biggest challenge for us is explaining to the public how we can help. Scientists are often not great at communicating science to politicians or the general public. We cannot afford to be bad communicators when the future of our planet is at stake.

WHERE DO YOU SEE YOUR OWN RESEARCH LEADING NEXT?

I will always focus on improving science education and making it more accessible to more people. I will continue to collect and analyse data to determine how to best teach outdoors, how to guide students through projects, and especially the unique characteristics of teaching adults rather than children.

DOES TRITON OFFER ANY OTHER PUBLIC OUTREACH SCHEMES?

Yes! We have a very active continuing education department for the community. We also have the Cernan Earth and Space Centre, which runs lots of science camps for school-aged children and hosts forums for the community. We commonly host career fairs with local businesses.

PATHWAY FROM SCHOOL TO GEOSCIENTIST

Sheldon says that a solid foundation in mathematics is a must. Many geoscience courses require one to two science subjects as well. Sheldon also recommends subjects such as art, computer science, philosophy and logic, which will help give a more well-rounded preparation.

HOW TO BECOME A GEOSCIENTIST

- Geoscience can be an undergraduate qualification in itself, but often elements of it are incorporated within other subjects, such as geology, Earth sciences, or some engineering courses.
- According to the QS Top University Rankings, the best universities for Earth sciences are ETH Zurich, MIT, Harvard, Cambridge and Oxford.
- There are plenty of apprenticeships available in the field of geoscience. This can be with organisations such as governmental environment bodies, energy companies, and consultancies.
- According to Indeed, the average annual salary for a geoscientist in the USA is $72,709, but given the wide range of geoscience roles, salaries vary considerably.

Triton College students conducting research in the Chicago River, collecting physical and biological data used to make planning decisions on the health of the river and the surrounding community.

Triton College students learning to survey and, unbeknownst to them, practising trigonometry in the process!

SHELDON'S' TOP TIPS FOR STUDENTS

01 – Stop thinking that science is for other people. Your questions about the natural world are important and science is a process that anyone can learn. It isn't about memorising facts; it is about going out and discovering new ones.

02 – Maths can be challenging but is important. Eventually, it will help you solve real problems when you apply it in a scientific way.

03 – Science is the best way to learn something new that no-one has ever learned before. It adds to our knowledge as a species and can make the world a better place for everyone.

HOW DID SHELDON BECOME A GEOSCIENTIST?

WHAT WERE YOUR INTERESTS AS A CHILD?

I always loved dinosaurs and nature. I didn't end up as a palaeontologist, but I at least get to teach about dinosaurs and evolution, and how they relate to modern society. I grew up near a river and my family spent every weekend in it, which I am sure is where my love of water science comes from.

WHAT INSPIRED YOU TO FOLLOW A CAREER IN GEOSCIENCE?

I didn't know about geoscience before college, as it isn't part of the core curriculum in my home state. In my first year of college, I took a class focusing on Mars that was taught by a geology professor. I became hooked. A geology field trip to Utah, in a landscape very different to the cornfields of my childhood, helped reinforce this.

WHERE HAS YOUR CAREER TAKEN YOU?

I've travelled across the USA, Canada, Ireland and the UK as part of my geoscience education. I love being able to travel somewhere new and figure out the history of the scenery I see. There is something majestic about piecing together the story behind the formation of a mountain, a desert or a volcano. Before I'd finished studying, I knew that sharing these experiences with others would be my life goal. That's what led to me focusing on geoscience education research for my doctorate, and the rest is history!

WHAT ATTRIBUTES HAVE HELPED YOU BECOME A SUCCESSFUL SCIENTIST?

Imagination. As a scientist, you need to connect things that others might think are unrelated. Experiences from one part of your life – a random class, an experience at a museum, or an interesting book – can be applied elsewhere and help solve real problems. Logical and critical thinking is important for research, but imagination is most important for kicking off the process.

HOW DO YOU OVERCOME OBSTACLES IN YOUR WORK?

I remind myself that I am solving real problems for real people, even if my work seems abstract at the time. I also remember to recognise the challenges faced by my colleagues and students. As a straight, white, cis-gendered male, I haven't experienced the same obstacles in my career that many of my colleagues have. It's important to listen to others and not be dismissive. I think some machismo remains in geoscience that could be pushing away people who don't look like me. I want to change this and make geoscience an inclusive discipline where all can succeed.

WHAT AMBITIONS DO YOU STILL HAVE TO ACHIEVE?

With a growth mindset the work never ends, as there are always new things to discover, new problems to solve, and new students to teach and learn from. I'd like to see diversity in STEM reflect the general population, first in my own community but ultimately at a global scale. Obviously, that's too much for just one person, but if I can move the needle just a little, I'll know I did my best.

START NOW TO REAP THE REWARDS LATER

DR SHAD NELSON AND HIS TEAM, BASED AT **TEXAS A&M UNIVERSITY-KINGSVILLE** IN THE US, ARE PASSIONATE ABOUT INCREASING THE NUMBER OF HISPANICS WITH ADVANCED DEGREES IN THE SCIENCES. THE **START NOW PROGRAMME** INVOLVES A UNIQUE TWO-WEEK INTERNATIONAL STUDY IN COSTA RICA, CENTRAL AMERICA, WHICH HAS ALREADY BOOSTED THE NUMBER PURSUING GRADUATE SCHOOL

HELPING STUDENTS GO FURTHER

The international study abroad, research-centred workshop experience in Costa Rica led to a higher percentage of student participants going on to graduate school, compared to students that only had a career-centred internship as an undergraduate in the same START NOW programme.

Students being trained by professors led to higher confidence and desire to pursue graduate school compared to peers seeking agriculture-oriented BS degrees.

- A total of 10 TAMU-Kingsville undergraduate students did research internships with non-faculty partners, 4 of which are now at graduate school (40%)
- A total of 9 TAMU-Kingsville undergraduate students attended the Costa Rica workshop led by faculty research mentors, 7 of which are now at graduate school (77.8%)

Shad concludes, "To increase the number of Hispanics with advanced degrees in the sciences, it is critical to create an atmosphere of faculty-mentored experiences for undergraduates in research.

International collaborative workshops and study abroad experiences can enhance student advancement for underserved minority populations in agricultural and science careers, and graduate school preparation."

There are too few underserved minority populations in critical science disciplines, such as soil, plant and agriculturally related sciences, and this is clearly problematic. It is of critical importance to increase diversity within the agricultural science disciplines for without them, progress that could be made within these fields is hindered – if everybody was given a fair opportunity at contributing, progress and scientific achievement would know no bounds.

Hispanic Americans are one of the minority populations that are underrepresented in agricultural sciences and research fields, so efforts are being made to improve undergraduate Hispanic participation, through experiential learning in soil science, plant science and environmental science. This is one of the key motivations behind the creation of the START NOW (Student Training in Agricultural Research Techniques by Novel Occupational Workshops) programme, which is designed to complement existing educational and academic programmes, and help Hispanic undergraduates become more competitive and better represented within agricultural sciences and research.

Dr Shad D. Nelson is a professor and dean based within the Dick and Mary Lewis Kleberg College of Agriculture and Natural Resources, at Texas A&M University-Kingsville in the US. He is a passionate leader of the START NOW programme and recognises how important such programmes are at fostering inclusion and presenting opportunities to underrepresented minorities within agricultural science.

WHAT MAKES START NOW SO UNIQUE?

The START NOW programme provides a life-changing opportunity for students to take part in an international study abroad

SHAD'S TOP TIPS FOR STUDENTS

1 – Be proactive, where possible. If you want to be part of a research project, then approach your teacher, explain your desire and they will likely help you in any way they can. Your tutors are there to help you and if you show that you are willing, you will be rewarded.

2 – Through the course of your studies and engaging in research, you will find that you have skills you never even knew about. There is a lot of untapped potential bubbling under the surface and drawing it out is one of the most satisfying feelings.

3 – Take every opportunity – if you can gain experience from a professional mentor then do so. Real-life training could change your life and help you to find a career that you love.

DR SHAD D. NELSON

Professor and Dean, Dick and Mary Lewis Kleberg College of Agriculture and Natural Resources, Texas A&M University-Kingsville, USA

FIELD OF RESEARCH

Soil, Plant and Water Sciences

RESEARCH PROJECT

START NOW is a programme that seeks to improve Hispanic participation in agriculture through experiential learning in soil science, plant science and environmental science. The students who are selected take part in an international study abroad experience in Costa Rica.

FUNDER

USDA-NIFA Hispanic Serving Institutions
(grant award no. 2016-38422-25542)

experience in Costa Rica. The programme introduces students to sustainable tropical agricultural practices and trains them through applied research-focused workshops. The undergraduate students are given the opportunity to work with other students and faculty mentors from four different Hispanic-serving universities: Texas A&M University—Kingsville, University of Texas at El Paso, Florida International University and University of Puerto Rico-Mayaguez.

HOW IS THE PROGRAMME STRUCTURED?

The START NOW programme is competitive, but once the students are selected, they go through preparatory training workshops before studying abroad. "In Costa Rica, students visit agricultural universities, research companies, farms and rural community businesses," explains Shad. "They learn about sustainable agricultural practices incorporating soil health and water quality management, highland and low-valley crop production and animal husbandry. Students are also trained in proper research sampling techniques, taking soil and water samples from various agricultural sites, followed by sample analysis at the Texas A&M University Soltis Center located in San Isidro, Costa Rica." Students work in collaborative teams and present their research findings prior to leaving Costa Rica.

WHY IS THE TIME STUDENTS SPEND WITH FACULTY SO IMPORTANT?

Many minority students are first generation college students and are often the first to obtain a college degree in their family – therefore, graduate school is not something many of them would consider automatically on entering college. "When students are engaged in research alongside a faculty mentor it has a profound impact on building their self-confidence, as they know an adult peer believes in their abilities," says Shad. "Students not only see their skills develop, they also learn they have an aptitude for science." Importantly, the two-week study abroad experience allows students and faculty members to spend quality time together, as well as having discussions during the discovery process. This can help students understand their potential and realise they are ready for graduate school.

WHAT HIGHLIGHTS AND SUCCESS STORIES HAS THE PROGRAMME SEEN SO FAR?

The START NOW programme has directly shown that if institutions want to increase the number of minorities in careers that require MS or PhD degrees, involvement with faculty mentors early on in the college experience is critical. "The impact and importance of faculty engagement by the two-week Costa Rica trip has led to a much higher percentage of students going on to graduate school than compared to those who only had a career-focused summer internship with US Department of Agriculture agency partners," explains Shad. "The number of doctoral graduates from minority Hispanic populations is very low and without programmes like this that support close faculty-student interaction, these numbers will continue to be suppressed in higher education institutions. Funding support for undergraduate research experiences with faculty mentor engagement is essential, otherwise the long-term impacts are fewer minorities considering and pursuing graduate MS and PhD degrees."

DOES THE PROGRAMME BENEFIT THE FACULTY AND INDUSTRY PROFESSIONALS WHO ARE INVOLVED?

Yes! Soil, plant, animal and environmental sciences are disciplines that require research and personal experiences that exist outside of the classroom. Information can be obtained from textbooks and conversations, but nothing beats working out in the field. The faculty members involved in START NOW are engaged in applied, hands-on learning workshops, which is beneficial to their own professional development. Of course, seeing underrepresented students exploring different fields of science for the first time is extremely rewarding.

STUDENT PROFILES

Name: Christopher Flores-Lopez
Major: Master of Agriculture Science, Agribusiness
Current role/studies: M.S. student working under the NSF-CREST Project

The faculty and staff at Texas A&M University-Kingsville (TAMUK) work hard to provide their students with opportunities to enhance their applied research skills. I became part of START NOW by taking advantage of those opportunities and have done my best to learn as much as possible from the experience.

The research my team and I worked on in Costa Rica focused on the water quality of the area. We took several water samples throughout the trip and measured the total amount of nitrogen and phosphorus in it.

One of the main highlights of the trip was the on-farm workshops. It was a unique experience to see how agriculture production varies in another country. Foundationally, agriculture in Costa Rica is the same as it is in the United States, however, there is a technological and resource gap between the US and Costa Rica. Therefore, many of the farmers and producers of the area had to come up with innovative ways to improve their production.

The workshop challenged my way of thinking. I had become so accustomed to the culture of the US that I had a hard time imagining life anywhere else. This trip challenged my world view!

I collaborated with students from Florida and Puerto Rico, as well as other Texas students. The students I keep in contact with seem to be doing very well. Meeting new people is always a blessing and our different backgrounds and life experiences helped me to expand my horizons and way of thinking.

After graduating, I am hoping that I can find a career that helps me accomplish two goals. One, to provide for my future family and me. Two, to give back to a community that has done so much for me.

While it may seem that a lot of what you are doing now is not realistic or does not matter, the work you are doing right now in your classes is helping you lay down the foundation for whatever you will do later on. Create a strong work ethic. Do the best you can and provide the highest quality work you can give. Never let anything wait until the last minute.

Name: Cynthia Puente
Major: Plant and Soil Sciences
Current role/studies: Master's in science

I collaborated with William Scally from Florida International University, under the guidance of Dr Nelson, to carry out research on the number of nematodes and species found in soil. My study involved comparing nematode counts found in different types of soils around Costa Rica – I looked at different locations and how the presence of these organisms promotes or hinders plant health.

I loved meeting, collaborating and learning with students from other academic institutions. Most of us had different degrees which allowed us to share different perspectives on agriculture sustainability. It was exciting to visit sustainable farms such as Don Juan Organic farm and Finca Luna Nueva, and tour Earth University.

The workshop helped me gain confidence to meet new people, establish relationships and work in a team. Listening to different opinions and suggestions made me grow as a person and bettered my internship experience.

The project motivated me to continue as a student researcher back at TAMUK. It convinced me that this pathway is the right one for me and that I wanted to continue my education in plant and soil sciences by applying for a master's degree.

I am ambitious and, in the future, I want to apply the knowledge I have gained to the wider community by joining the United States Department of Agriculture, working in plant protection for the Animal and Plant Inspection Service, or becoming an agricultural specialist for US Customs.

The one piece of advice I would give to budding scientists is to get out of your comfort zone. Challenge yourself! If you like plant and soil sciences, then ask faculty members about research opportunities – it is a great way to gain experience and will help you decide whether it is the right pathway for you.

Name: Jonah E. Trevino
Major: Horticulture
Current role/studies: M.S. Graduate Research Assistant – Studying Therapeutic Horticulture

My project in START NOW was concerned with water quality. We took water samples from multiple rivers and streams near agricultural land, natural areas, and near small population towns. We checked the water for nitrogen and phosphorus levels and presented our results.

The main highlight was visiting agricultural farms. It was amazing seeing sustainable agricultural practices first-hand. I also enjoyed the trip to Earth University, as they showed their sustainable practices to us; seeing what students did to educate themselves as well as provide for the university blew my mind.

I had to come out of my shell quickly. Although we were only there for two weeks, I soon made friends and the experience helped me realise I was able to adjust to new environments with new people quickly.

Dr David Sotomayor, from University of Puerto Rico at Mayaguez, and Guadalupe Alvarez Rodriguez, from The University of Texas at El Paso, both greatly impacted my experience. When we were stuck after collecting our data, we were ensured that there is always an answer hidden in the numbers. This was a great insight that has shaped my work since.

START NOW has encouraged me to keep an open mind when deciding what I want to do in life. When I was younger, I was always obsessed with the thought of having a self-sufficient homestead, but I would have never thought my curiosity for it would help me continue my education. I am excited about the future.

My dream is to complete my PhD, become a Horticultural Therapist-Registered, get some work experience in my field, and start my own therapy farm. The internship has helped shape my future career path and I would like to work with at-risk youth, rehab patients, or mental health patients with vocational therapy sessions. Of course, things always change, but that is the plan at the moment!

One thing I learned after the internship is that sometimes we don't entirely know what we want. I encourage students to embrace challenges and make things happen, whether that be by attending meetings for internships, or improving your grades to give yourself a better chance of getting an internship. Do not wait for things to happen; START making them happen NOW!

Students outside Texas A&M Soltis Center, Costa Rica.

Analyssa Camacho trying a Costa Rican pineapple. Analyssa is now studying for her master's.

Students taking water samples in Costa Rica.

HOW TO BECOME A SOIL SCIENTIST

- The Soil Science Society of America is a brilliant resource for those interested in learning more about the field: **https://www.soils.org/**

- The United States Department of Agriculture has a section dedicated to careers in soil science, from what it entails through to how to become a soil scientist: **https://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/edu/?cid=nrcs142p2_054277**

- The average salary for a soil scientist is $58,652, with positions in the field typically spanning from $39,000 to $91,000, depending on the level of experience.

PATHWAY FROM SCHOOL TO SOIL, PLANT AND WATER SCIENCES

Shad believes that for those interested in working in the field of soil, plant and water sciences, studying subjects such as chemistry, biology, agricultural science, horticulture and environmental science is beneficial.

https://www.careerexplorer.com/careers/soil-and-plant-scientist/how-to-become/

Darium Marte De Jesus taking soil samples in Costa Rica.

BUILDING INCLUSIVITY INTO ASTROPHYSICS

MANY STEM FIELDS CONTINUE TO SUFFER FROM A LACK OF DIVERSITY – PEOPLE FROM MINORITY BACKGROUNDS MISS OUT ON REWARDING CAREERS AND SCIENCE MISSES OUT ON EXCEPTIONAL TALENT. **DR RODOLFO MONTEZ JR.** AND **CHRISTINE CROWLEY**, OF THE **SMITHSONIAN ASTROPHYSICAL OBSERVATORY** IN THE US, ARE ADDRESSING THIS ISSUE THROUGH AN INNOVATIVE INTERNSHIP PROGRAMME THAT GIVES STUDENTS A REAL-LIFE TASTE OF A CAREER IN RESEARCH

Dr Rodolfo Montez Jr. is an astrophysicist at the Center for Astrophysics' Smithsonian Astrophysical Observatory (SAO), in Cambridge, Massachusetts. He and Christine Crowley, the SAO's Fellowship Program Director, run the SAO Latino Initiative Program (SAO LIP), an inspiring summer internship scheme that encourages local undergraduates from under-represented backgrounds to pursue careers in STEM.

THE PROGRAMME'S ORIGINS

"I vividly remember being one of only a handful of budding Latino astronomers at national meetings in the early 2000s," says Rodolfo. "I found it very disconcerting. These days, it is more common to see young astronomers from all backgrounds, but we are still below expected representation." This issue of inclusivity is apparent across much of STEM, but especially within the 'hard sciences'. "Talented undergraduates from local communities are largely not choosing physics or astronomy," says Christine. "This is particularly true among promising STEM majors in the Latino and African-American communities."

Christine and Rodolfo are addressing the false perception that there are few career opportunities within physics and astronomy for members of these communities. "The best research programmes are always the most diverse programmes," says Christine. "We found that students in the Urban Louis Stokes Alliance for Minority Participation in STEM enriched our programmes by providing original research and unique perspectives, and participants helped support their peers too. This inspired me to begin the Latino Initiative Program, aimed specifically at local minority undergraduate students."

Rodolfo agrees, motivated by his own personal experience. "As an under-represented minority in STEM, I have always been interested in efforts to increase representation," says Rodolfo. "Since I was a graduate student, I have participated in and designed programmes that aim to improve representation in STEM, including mentor and research training and network building. When I arrived at the Smithsonian Astrophysical Observatory and learned about the LIP from Christine, I knew I had to get involved."

THE SAO LATINO INITIATIVE PROGRAM

The SAO LIP involves a summer internship that immerses students within important research, supported by an extensive mentor system. "A key element of the programme is that students are incorporated into significant research projects within astronomy and astrophysics," says Christine. "Most students are amazed at the level of responsibility they are given." She and Rodolfo believe that this first-hand experience of scientific research is the most effective strategy for inspiring their future career paths.

The SAO LIP is also flexible in the academic backgrounds it considers taking on, not limiting itself to applicants from 'hard science' backgrounds alone. "We take on students from many academic fields, so there are steep learning curves involved regarding learning the languages of astronomy and computer programming,"

HOW TO BECOME AN ASTROPHYSICIST

- According to QS World University Rankings, the best universities for physics and astronomy are MIT, Harvard, Stanford, Cambridge (UK), and California Berkeley.
- There are internship programmes available for astrophysics across the world. In the US, this includes the BMSIS Young Scientist Program, CRESST in Baltimore, and the Lunar Planetary Institute Summer Intern Program.
- According to PayScale, the average US astrophysicist salary is around $84k.

says Rodolfo. " We offer crash courses and bootcamps to bring students up to speed on these, and they always learn surprisingly fast."

Christine agrees with this encouraging trajectory. "Despite many students beginning without significant programming or research experience, with the right mindset and support, many exceed expectations," says Christine. Understandably, students can be daunted by the responsibility and the decision making required by scientific research, but the programme gives them the confidence needed. "The Program is designed to ensure success by providing a multi-layered approach to mentoring," explains Christine. "Students have a peer mentor, STEM mentor, and two research advisors and, of course, the most critical element is the support of our wonderful institutional partner, the University of Massachusetts, Lowell."

THE INTERNSHIP'S IMPACT

"This programme changes lives," says Christine. "It helps widen students' perspectives and possible career paths, provides them with a sense of belonging, and boosts their confidence." Rodolfo has also seen first-hand the personal growth the programme brings. "It never ceases to amaze me to see how the students progress," he says. "It bridges the gap between dry academic journals and the real-life people who make science happen. I find it so rewarding to be a part of this realisation of their potential, and to know that the experience they gain will be carried forward in their careers."

It is not only the interns who benefit, but also the academic community at large. "The students in the LIP challenge preconceived notions of learning, advising and mentoring within academia," says Christine. "Additionally, many academics are seeing the benefits of providing opportunities for students from majors other than physics or astronomy. There is no doubt that the programme has not only increased awareness about the existing lack of diversity, but also the talent and capabilities of locally undergraduates."

FUTURE DIRECTIONS

"The vast majority of our interns go on to have a thriving career in STEM – some interns have even been hired by the Centre as employees," says Christine. "The programme has exceeded expectations, not just through providing opportunities for students but also by contributing to ongoing discussions about inclusivity. At a personal level, it is very satisfying to help young members of our community achieve their full potential."

In addition to its many successes to date, Christine and Rodolfo hope to take the LIP further. "The programme always strives to improve," says Rodolfo. "We are working to expand the professional development opportunities available, and also curate these offerings for individuals to ensure maximum positive impact. We also want to connect further with other summer research programmes at the Center for Astrophysics to improve the experience for all students. These efforts will build on the tremendous impact that the LIP has already had."

DR RODOLFO MONTEZ JR.

Astrophysicist, Chandra X-ray Center

CHRISTINE CROWLEY

Master of Education (M.Ed.)
Director of SAO Latino Initiative Program

Smithsonian Astrophysical Observatory, Center for Astrophysics, Harvard & Smithsonian, Cambridge, Massachusetts, USA

FIELD OF RESEARCH

Astrophysics

PROJECT

The LIP Summer Internship Program encourages under-represented young people from the local community to pursue careers in STEM.

FUNDERS

National Science Foundation, Smithsonian Latino Center Latino Initiative Pool

This programme received federal support from the Latino Initiative Pool, administered by the Smithsonian Latino Center. This material is based upon work supported by the National Science Foundation under Grant No. 1745460.

HOW DID RODOLFO BECOME AN ASTROPHYSICIST?

As a child, I was interested in natural science and tinkering with my toys. I liked amphibians and reptiles. There was a time I would remove geckos from neighbours' houses for the low rate of 50 cents a gecko!

I was drawn to science early on, but I was turned towards accounting by my high school guidance counsellor. I was well into my accounting programme when I took an astronomy course to fulfil my science requirements. It was all I could talk about, so my friends told me to do that instead!

Creativity has played a big role in my success. I find it most rewarding when I make a new discovery by approaching the data with an innovative analysis – a creative perspective brings evidence to the surface and opens a new window into the universe.

My dream astrophysics project would be a next generation space telescope like the proposed Lynx observatory. This X-ray telescope would be a successor to the telescope I currently help operate, Chandra. The sensitivity of this telescope will throw the doors open to so many new discoveries.

I like to crochet, draw and cook. Crocheting gives me something to do while I mull over a problem, drawing gets me 50% of the way there but work is still on the periphery, while cooking takes me to a different head space entirely. I have also done fencing, ballroom dancing and graphic design!

MEET THREE SAO LIP ALUMNI

NAME: Arielle Joasil

MAJOR: Electrical Engineering

CURRENT ROLE: Graduate Research Assistant in the CACT (Center for Advanced Computation and Telecommunications); Master's student in Electrical Engineering at UMass Lowell

I was excited by what the LIP had to offer, and found that my electrical engineering skills were also applicable to problems in astrophysics. I also wanted to learn more about the researcher lifestyle.

For my first summer at the SAO, I investigated how interactions between planets can remove moons from their host planet's orbit. My advisor and I found that it is likely that many white dwarfs (small stars) in the Milky Way are polluted by these 'lost' moons.

During my second summer, I worked on research and served as a peer mentor to other students, acting as a point of liaison for them, their advisors, and the programme coordinator. I also coordinated weekly computer programming sessions.

The programme was challenging intellectually, and I had to use my skills to build a foundation of understanding in unfamiliar territory. I found it exciting to expand my knowledge and solve a variety of problems.

A particular highlight was working with my advisor, Dr Matthew J. Payne; his support showed me how to do great work as a researcher, which really sparked my fascination.

Despite being a shy person, I found that stepping outside my comfort zone during the LIP and talking with different people helped me develop. This expanded further when I realised that I really enjoy mentoring others.

I would like to pursue a PhD in electrical engineering and complete work related to data science, machine learning, or signal processing. Ultimately, I hope to become a professor, which would allow me to conduct interesting research and mentor students.

Taking a chance and stepping outside your comfort zone can be very powerful. Your dreams may scare you, but you can achieve them – have faith in yourself!

PATHWAY FROM SCHOOL TO ASTROPHYSICS

Rodolfo says that an understanding of maths and physics is essential for astrophysics, and that computer programming can be very useful. He recommends rounding out one's education with creative pursuits as well, either within school or as extra-curricular activities.

Christine says that in addition to a robust scientific foundation, a scientist also needs strong creative skills for writing about and publicising their research. She recommends taking courses such as English and public speaking to develop these skills.

TOP TIPS FOR STUDENTS

RODOLFO'S TOP TIP:

- The world is changing rapidly and we no longer need to compromise our identities – be yourself and celebrate who you are.

CHRISTINE'S TOP TIPS:

- Remember, there are many ways to have a career in science without getting a Ph.D. Tutors and mentors can offer you invaluable advice to set you on the right path for you.
- Experiment with different career paths through internships.
- Learn to persist – obstacles are a natural part of your pursuit.
- If you can, spend a year abroad as a student or an employee.

NAME: Fernando Mazzoni

MAJOR: Physics

CURRENT ROLE: M.S. Physics at University of Massachusetts Lowell

I applied to the programme because I wanted to carry out research and get to know more students and scientists from similar backgrounds to myself.

My research focused on understanding X-ray emissions from dwarf carbon stars (stars with more carbon than oxygen in their atmosphere). Unexpectedly, we found that these stars emit consistent X-rays, meaning they had probably had mass transferred from another star in their lifetime.

My internship also involved meeting with my peers in workshops and attending plenary talks and seminars. At the end of the internship, we gave poster presentations of our research – I was very nervous beforehand, but it felt great discussing the research and left me feeling accomplished and successful.

The internship was my first time learning about astrophysics, undertaking real research, and using the computer programming language, Python. I lacked confidence at first, but the programme made a great effort in making sure I was comfortable, and I quickly caught up on the necessary concepts.

I met my peer mentor regularly and my advisor weekly. They were both friendly, helpful and understanding.

Now, I can perform research-level analysis using Python, which is an invaluable skill. I have a much greater understanding of how professional research is done, and a firm grasp of the skills I need to become a STEM researcher.

Looking to the future, I hope to better understand the world around me and help others do the same. A lot of the skills I obtained from the programme can be helpful across a wider range of fields, and I hope to use them to support my community.

Things may seem overwhelming at times, but breathe, relax, and try your best. I recommend going for any opportunity that interests you – it never hurts to apply.

NAME: Shanelle Samuels

MAJOR: Chemical Engineering

CURRENT ROLE: Process Development Associate at The Broad Institute of MIT and Harvard.

This internship immediately caught my eye as I wanted to get some experience within the scientific community.

My research focused on assembling findings from experimental and theoretical studies that help detect molecules found within distant planets' atmospheres. This will help researchers to identify the types of planets their instruments pick up.

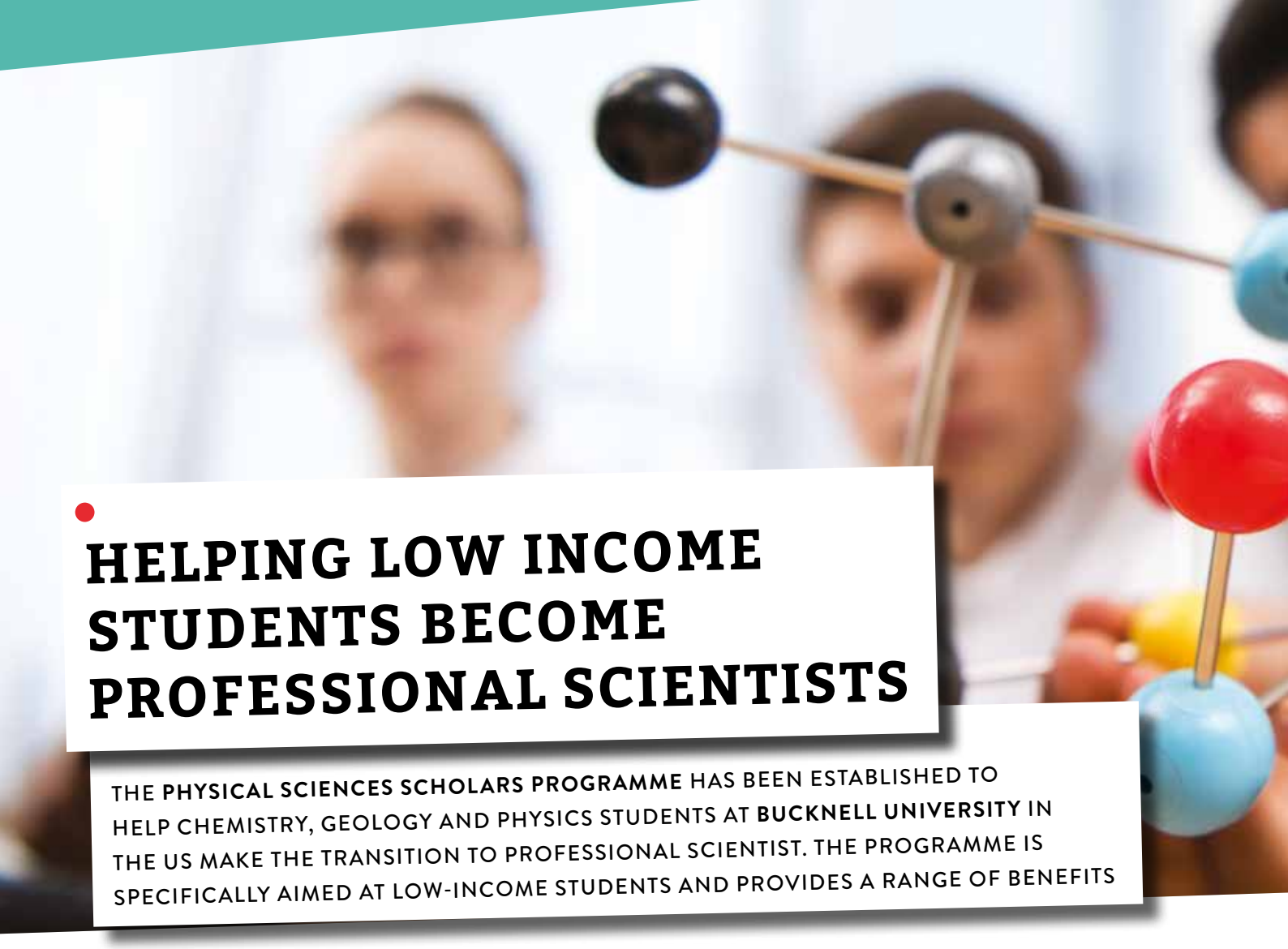
We had a weekly computer programming class where we learned to use Python. It was my first time learning to program in such depth and it was very worthwhile.

I received a lot of support from fellow scientists and students, especially the post-doctoral researchers who helped me feel welcome. I was able to go to them for help at a moment's notice whenever things became difficult.

I learned a lot about how to work as part of a team to accomplish a goal. Computer programming has also come in useful with transitioning to other coding languages in subsequent classes. I am very proud of how far I came, especially within computer programming.

I hope to become a process engineer, utilising the skills I learned at this internship. Ultimately, I aspire to be a part of the Harvard Smithsonian as a fellow academic.

Soak up everything you can from the experience, and make sure to enjoy it as much as possible.



HELPING LOW INCOME STUDENTS BECOME PROFESSIONAL SCIENTISTS

THE **PHYSICAL SCIENCES SCHOLARS PROGRAMME** HAS BEEN ESTABLISHED TO HELP CHEMISTRY, GEOLOGY AND PHYSICS STUDENTS AT **BUCKNELL UNIVERSITY** IN THE US MAKE THE TRANSITION TO PROFESSIONAL SCIENTIST. THE PROGRAMME IS SPECIFICALLY AIMED AT LOW-INCOME STUDENTS AND PROVIDES A RANGE OF BENEFITS

Unfortunately, despite our being firmly within the 21st century, there remain many underrepresented groups and marginalised populations in society. These groups include people of colour, those with physical or mental impairments, women, people with LGBTQ+ status and the economically disadvantaged. There is no single reason why these groups are underrepresented, which is why there is no simple one-size-fits-all solution and why it is still an issue that exists today.

However, there are reasons to be positive. The recent Black Lives Matter protests that took place in countries around the world in the wake of George Floyd's death show a deep acknowledgement of the disparities that continue to pervade many areas of society. Indeed, efforts are being made to make workplaces more diverse and, while there is still so much more that needs to be done, we are at least headed in the right direction.

One example of this is the Physical Sciences Scholars (PSS) programme that is hosted by Bucknell University in Pennsylvania, US. PSS is funded by the National Science Foundation and was established in 2017 with a view to help students who are interested in majoring in physical sciences, including chemistry, geology, environmental geosciences, physics and biophysics.

HOW DOES PSS HELP STUDENTS?

PSS awards up to $10,000 each year to students from families of low to moderate incomes. The key idea behind the programme is to help low-income students transition from studying at Bucknell University to becoming professional scientists. Professor JiaJia Dong is the Principal Investigator of the programme and she works alongside Professors Karen Castle and Mary Beth Gray. The three of them pool their passion, knowledge and expertise to ensure that the student scholars are given the dedicated and sustained support and mentorship they need to succeed.

WHAT ARE THE BENEFITS OF BEING A STUDENT SCHOLAR?

Being a student scholar and receiving an award of up to $10,000 per year removes the dependence on loans and employment. This lessens any financial anxieties and frees up time so the students can dedicate themselves to the subject they are studying and take advantage of career building opportunities in research and teaching labs. There is a first-year foundation seminar course that has been specifically designed for the group of scholarship students that is linked to the Discovery Residential College – a themed living-learning community where PSS scholars spend their first year on campus.

The college also functions as a means of exploring how science, technology, engineering and mathematics change the world every day. There is a host of foundation seminars, including The Universal Machine (which focuses on how science impacts society), and Illusions! (which examines various types of illusions that demonstrate how perception very rarely aligns with reality).

HOW DOES PSS ACCELERATE THE TRANSITION TO PROFESSIONAL SCIENTIST?

The programme provides exclusive mentorship and a host of networking resources to help students become professional scientists at an accelerated rate. By working closely with the Center for Career Advancement, the team facilitates career placements, internship and externship opportunities. In addition, there is additional funding for a 10-week summer research experience and travel funds that enable students to present their work at academic and professional conferences.

MEET THE THREE RESEARCHERS LEADING THE PHYSICAL SCIENCES SCHOLARS PROGRAMME

PROFESSOR JIAJIA DONG

Principal Investigator
Department of Physics and Astronomy
Bucknell University, USA

I am the Principal Investigator of the PSS programme, where I oversee the running of the project. I also participate in mentoring student research, and conduct student surveys to track the progress of the participants.

My involvement in the programme is a result of our wanting to recruit a more diverse student body to Bucknell University. We specifically want to attract students who are keen to pursue degree programmes in the physical sciences, such as chemistry, geology, physics, biophysics and environmental geosciences.

The 12 students of our first cohort have just completed their first year at Bucknell. Part of their learning experience was impacted by COVID-19, when all classes shifted to remote instruction in mid-March, 2020. However, it has still been motivating to see some of the students embrace the learning opportunities and join the faculty research team.

I wasn't interested in becoming a scientist until mid-way into my doctoral programme when I found my own research topic. It was exciting – and rewarding – to be able to ask a question no one had asked before and to then find a way to answer that question. Part of the PSS programme is to see whether student research can help establish students' self-identification as a scientist earlier in their college career so that students can persist and thrive in the programme. As someone who found passion in science through actually doing the research beyond taking lectures, I find it exciting that the PSS programme can create such opportunities for the students.

My eureka moments, both big and small, have often had student involvement. Finding a good way of explaining a complicated idea after discussing it with students and figuring out some research topics from students' questions are two particularly memorable highlights.

JIAJIA'S TOP TIPS FOR STUDENTS

1 Do what interests you rather than what appears to have good job prospects. I recently realised that most of my time is spent thinking about research and teaching, and if this wasn't something I am passionate about, it would have been difficult to have done it for as long as I have! I also wouldn't be as good at it as I believe I am!

2 Hone your writing at every opportunity. The majority of jobs involve writing of some sort, with many different styles depending on the type of job. You might need to write emails and reports, and being able to communicate in an organisation through written messages is an important factor in determining an individual's competency.

PROFESSOR KAREN CASTLE

Professor of Chemistry
Department of Chemistry
Bucknell University, USA

I am a co-principal investigator of the PSS programme and have been working very closely with the first cohort of PSS students. I taught a class that was specifically designed for the PSS students last Autumn – a first-year foundation seminar entitled Science and Serendipity. In this course, we looked at how some of the greatest scientific discoveries were made throughout history, exploring how progress is made in science and what it means to be a good scientist. I was also the academic advisor for all the PSS students. I have worked with individuals and groups of students to help them navigate their first year.

I have wanted to run this programme for more than a decade and was thrilled when the National Science Foundation decided to help us make it a reality! Nationwide, we need to do a better job at recruiting talented students from underrepresented groups into the sciences. This programme is an attempt to make high-quality education in the physical sciences more accessible to students with a high financial need. We are also trying to learn new ways to help students achieve academic success in STEM fields.

The foundation seminar course was one of the greatest success stories so far. Having all the PSS students together for one of their courses was a great way to help them successfully transition to college. They all made it through their first year and all still intend to major (or double-major) in a STEM discipline! We have already learned a lot from the first cohort and have a much better understanding of the kinds of challenges students face in their first semester at college. By studying how they self-identify as scientists and how that perception changes over time, we are learning how we can better help STEM students with mentoring.

It took me a while to figure out that science was the right path for me. Chemistry is a difficult subject and I didn't have much of a background in it when I started college. I felt like everyone else knew more than I did and I didn't have much confidence in my abilities. Eventually, I realised that most people in introductory courses feel the same way. After taking a few courses in chemistry, physics and mathematics, I began to love problem-solving. Once I experienced research for the first time, I was truly hooked.

After months of struggling with the material for one of my college courses, I was studying for a final exam when thermodynamics all of a sudden made sense to me. It's hard to explain, but I went from not getting it at all to suddenly seeing all the patterns unfold. I'm sharing this experience to point out that science and maths can be really challenging, but if you keep working at it, you can overcome the challenges. Of course, I've had many eureka moments in my research lab and that is one of the main reasons I love my chosen career so much. There is always something new to discover and I love knowing that I will never stop learning new things.

KAREN'S TOP TIPS FOR STUDENTS

1 Keep in mind that if science is something you find interesting, irrespective of which particular subject, you can be a scientist! There are many people out there who want to help you learn, grow and succeed.

2 It takes time for most people to figure out what they are best at. It also takes time to learn and develop the skills you need to be successful. However, if you are motivated to learn, put the effort in, and seek out help and guidance, anybody can succeed in STEM.

3 We need a constant supply of new ideas in the natural sciences. The best way to make progress on real problems is to approach them from multiple angles through multiple lenses and we need as many perspectives as possible. Yours is as valid as anybody else's.

Some of the Physical Sciences Scholars are geology and environmental geosciences majors. A fun team building activity was to explore the local geological sites around central Pennsylvania.

It is important to keep students engaged, and one effective tool is to develop a sense of belonging in a scientific community and the identify as a scientist. The PSS programme builds a community among the participants. In the picture above, the community is enjoying an afternoon of kayaking along the Susquehanna river.

PROFESSOR MARY BETH GRAY

Professor of Geology
Department of Geology
Bucknell University, USA

I am a co-principal investigator of the PSS programme. With my collaborators, I am active in mentoring, conducting related educational research, and developing and teaching a course specifically designed for physical sciences scholars entitled Curiosity: The Driving Force of Science. The course explores frontiers of knowledge in the physical sciences and considers the myriad ways scientists devise research questions. The course is writing-intensive and incorporates interviews with physical scientists, video and poster group projects and career development components.

We seek to attract a diverse group of academically talented students in the physical sciences. Our programme is designed to cultivate a strong supportive community, provide logistical, mentoring and scholarship support for students over the length of their undergraduate studies with the intent of optimising their chances of success in their science careers.

I am inspired by the physical sciences scholars that I have come to know. I respect their commitment, enthusiasm and curiosity.

When I was younger, I took a course in college that ignited my passion for geology. Later, I had a superb research mentor who helped me recognise my capabilities and encouraged me to pursue a career as a geoscientist.

Discovering geosciences as an undergraduate was such a wonderful surprise and it changed the direction of my life. As a geoscientist, I have conducted research throughout my career and have had many exciting moments of discovery along the way. It is especially fulfilling to be able to work with undergraduate research students and witness their moments of discovery as well.

MARY BETH'S TOP TIPS FOR STUDENTS

1 Believe in yourself and your capabilities. Seek out supportive mentors along the way who will challenge you to grow as a professional scientist.

2 Be tenacious! Inevitably, there will be setbacks, but you should not let these discourage you. Instead, learn from them and redouble your efforts!

3 Above anything else, you should enjoy the process of discovery. Being a scientist is all about uncovering things that were previously unknown – it is one of the best things about being involved in the sciences.

PHYSICAL SCIENCES SCHOLARS PROGRAMME

SITES:
Bucknell University, Pennsylvania, USA

AIM:
To support students from families of low to moderate incomes who are interested in majoring in the physical sciences, including chemistry, geology, environmental geosciences, physics and biophysics.

FUNDER:
The National Science Foundation

USEFUL LINKS

- Physical Sciences Scholars Programme: www.bucknell.edu/admissions-aid/tuition-fees-financial-aid/scholarship-programs/physical-sciences-scholars-program
- Discovery Residential College: www.bucknell.edu/life-bucknell/first-year-experience/residential-colleges/discovery-residential-college
- Bucknell University: www.bucknell.edu

The PSS cohort explores Reptile Land.

MAKING TEACHING AS INCLUSIVE AS POSSIBLE

IT'S COMMONLY KNOWN THAT MANY FIELDS OF STEM, IN PARTICULAR ENGINEERING AND COMPUTER SCIENCE, SUFFER FROM A LACK OF DIVERSITY. TACKLING THIS IS A MAJOR CHALLENGE, SO **DR CHRISTINA H. PAGUYO** AND **DR VALENTINA ITURBE-LAGRAVE**, FROM THE **UNIVERSITY OF DENVER** IN THE US, ARE USING INNOVATIVE SOCIAL SCIENCE TO HELP TEACHERS EMBRACE INCLUSIVE TEACHING TECHNIQUES

TALK LIKE A SOCIAL SCIENTIST

DEI – Diversity, Equity and Inclusion, to prevent marginalisation of under-represented groups

INCLUSIVE TEACHING – embraces students as whole beings to create relevant, meaningful, and accessible learning experiences that recognise students' differences as enriching sources of diversity

INTERSECTIONALITY – understanding the complex power dynamics of how a person's multiple social identities intersect to affect their whole lives

LGBTQIA - lesbian, gay, bisexual, transgender, queer/questioning, intersex and asexual

POSITIONALITY – understanding how people's social position shapes their identities and the power they hold in certain contexts

PRIVILEGE – the benefits and advantages given to those whose social identities are shared with the dominant culture

OPPRESSION – the systematic and systemic suppression of a group by the group in power

QUALITATIVE DATA – observational or narrative data that explains and characterises, collected through (for example) field notes, video recordings, interviews or focus groups

QUANTITATIVE DATA – numerical data that can be used for calculations and statistical analysis

SOCIAL DESIGN EXPERIMENTS – partnerships between researchers and (for example) teachers that facilitate learning and development through an evolving design and measure process

SOCIAL SCIENCE – the study of human society and social relationships

Passionate about inclusive teaching and determined to tackle challenges with optimism and collaboration, Dr Christina H. Paguyo and Dr Valentina Iturbe-LaGrave, of the University of Denver in the US, lead a National Science Foundation-funded research project designed to make engineering and computer science more inclusive through transforming the way it is taught. The first aim of this programme is to train professors to become stronger, more inclusive teachers, to help all students to become more successful. "The second aim of our research is to help professors and students understand how diversity, equity and inclusion (DEI) bolster engineering and computer science professions," says Christina. "We accomplish this through re-designing aspects of the curricula to include critical aspects of DEI that validate the life-experiences and identities of students," says Valentina.

INCLUSIVE TEACHING

Valentina and Christina are spearheading inclusive teaching and assessment initiatives. This is a method of teaching rooted in the understanding that everyone in a classroom brings their values, cultures, genders and ethnicities with them, and these have an impact on the learning experience.

"Think about all the different parts of your identity and how they combine to make up your whole self," says Valentina. "These are your intersecting social identities. For example, I am a cisgender, female scholar and also a mother of four." Your intersecting social identities shape how you engage with learning – for instance, you might have experience of cultures, languages, disability, or discrimination that others do not. "These factors influence how people make meaning and learn about the world around them," adds Valentina. "For example, you might have more insight into accessibility if you have a physical condition, or different conceptual processing if you speak another language." An important starting point for Valentina is that, "everything we learn is processed through the lens of our social identities, and many of these identities change over time, that is called positionality." You may have been born as an able-bodied individual and survive an illness or accident that changes your mobility later in life. This is a positionality change because your social identity now includes your perspective as a differently-abled bodied person.

CHRISTINA AND VALENTINA'S TOP TIPS FOR STUDENTS

1 If you come across someone in a career that interests you, consider sending them a professional email asking if they would give you insights into their career pathway. Though it may feel uncomfortable to reach out, such contact can help you understand the pathways available and begin growing your network.

2 Don't feel you have to follow in anyone's footsteps. Follow your heart and harness the wisdom of the people and resources you find along the way.

3 Think outside the box, and don't be deterred by any challenges you come across.

SOCIAL SCIENCE

While social scientists can study both qualitative and quantitative data, Christina and Valentina tend to focus on qualitative data. "Researchers who study qualitative data are trained to analyse how people make meaning of processes and situations," says Christina. This sort of data can uncover very important insights that are challenging for quantitative data to capture.

This approach is seen in their work on social design experiments. "Designing for equity is the goal of these experiments. We create interdisciplinary partnerships where researchers and partners study teaching and learning through an ongoing and repetitive process of design, measurement and feedback," says Christina. "These tools help researchers design educational systems where DEI values support student learning."

THE RESEARCH

Firstly, Christina and Valentina recorded interactions in the classroom and interviews with the class professor, and then played the recordings back for the professor to reflect on. Secondly, they took field notes to complement the recordings and interviews. By working together, the researchers and professors used the video to identify the teaching strategies in play, any barriers to DEI inadvertently fostered, and where there was capacity for improvement. "Through watching themselves teaching and through prompts that promoted self-reflection, professors were able to identify critical issues in their classrooms," says Valentina.

OUTCOMES

"There were two significant findings from our research," says Christina. "First, that universities need to create optimal conditions for professors to learn, as well as students, to help them become better teachers. Second, that DEI issues can come alive in any academic discipline, even computer science and engineering."

A lack of diversity in these fields has led to some major oversights in recent years. For instance, early facial recognition software did not recognise the faces of black people. "Even though these seemingly objective professions may appear to be neutral and solely technical, scientists and engineers can unintentionally create discriminatory infrastructures if they do not engage with DEI," says Christina.

Facilitating honest conversation and genuine self-reflection, Christina and Valentina's inspiring work reminds us that we all have a role to play in making communities – including those in academia – more inclusive. We can learn together to succeed together.

DR CHRISTINA H. PAGUYO

Director of Academic Assessment, University of Denver, USA.

FIELD OF RESEARCH

Assessment, Learning Sciences, Education Policy, DEI

DR VALENTINA ITURBE-LAGRAVE

Director of Inclusive Teaching Practices, University of Denver, USA

FIELD OF RESEARCH

Inclusive Teaching Practices; Power, Privilege and Oppression; Change Leadership.

JOINT RESEARCH PROJECT

Cultivating Inclusive Identities of Engineers and Computer Scientists: strengthening faculty competence in inclusive pedagogies through formative assessments of video records.

FUNDERS

National Science Foundation, Interdisciplinary Research Institute for the Study of (in)Equality (IRISE)

ABOUT ACADEMIC ASSESSMENT

ACADEMIC ASSESSMENT, CHRISTINA'S SPECIALTY, IS THE PROCESS OF USING EVIDENCE TO UNDERSTAND AND IMPROVE STUDENT LEARNING IN ACADEMIC PROGRAMMES. IT CAN BE USED TO SEE WHETHER TEACHING TECHNIQUES FULFIL THEIR INTENDED PURPOSE, AND WHETHER THERE ARE ANY UNADDRESSED 'GAPS' IN THE LEARNING EXPERIENCE. CHRISTINA EXPLAINS WHY ACADEMIC ASSESSMENT HAS A CRUCIAL PLACE WITHIN TEACHING.

Assessment can be transformative because it illuminates information that would otherwise remain in the shadows. From our video consultation research, for example, assessment helped a professor see how he unintentionally fostered racially segregated teams through the use of implicitly biased technology. In this case, assessment helped 'transform' how the professor perceived students and he used DEI to re-design teams.

Traditional academic assessment focuses on learning outcomes, whereas inclusive assessment focuses on how professors can foster stronger relationships so students can engage in deep learning. Students need to be able to connect with academic content, their classmates, the teacher, and their future selves. Inclusive assessment helps build these connections, beginning with enabling professors to view students as complete human beings with dynamic and multi-faceted lives beyond the classroom.

We need to train engineers and computer scientists to understand how their designs affect all communities in society, particularly populations who are economically and politically vulnerable. We need to increase the number of Black, Indigenous and People of Colour (BIPOC), women, LGBTQIA, and people with disabilities within engineering and computer science, in particular in leadership, activist, and technical roles. We also need to train scientists how to value and collaborate meaningfully with people from all backgrounds so that STEM continues growing into a human-centred profession dedicated to improving people's lives. Together, these will ensure there is a diversity of perspectives and a socially-minded driving force shaping the future of STEM.

My passion is to help people thrive and learn with their head, hands and hearts. I enjoy building and sustaining meaningful relationships with people, because what we can create through collective endeavours is much greater than what any one individual can do alone. What I find most challenging is navigating political landscapes when stakeholders have conflicting motives, or when people have stereotypes about assessment that I work hard to dismantle. But, I also find this motivating because I love problem-solving and figuring out how to transform challenges into opportunities, like turning lemons into lemonade!

ABOUT INCLUSION

INCLUSION REFERS TO MAKING SURE THAT PEOPLE FROM ALL BACKGROUNDS ARE INCLUDED WITHIN SOCIETAL STRUCTURES, SUCH AS IN CLASSROOM LEARNING AND ACADEMIA. THIS IS BENEFICIAL NOT ONLY FOR PEOPLE FROM UNDER-REPRESENTED BACKGROUNDS, BUT ALSO FOR SOCIETY AS A WHOLE, AS IT ENCOURAGES A GREATER DIVERSITY OF KNOWLEDGE AND APPROACHES TO PROBLEMS. VALENTINA TALKS ABOUT THE IMPORTANCE OF CREATING A MORE INCLUSIVE LEARNING ENVIRONMENT WITHIN ACADEMIA.

As a social scientist, I believe we best measure success through sustained culture shifts and academic changes. For example, nowadays there is a very open conversation about the lack of women in STEM fields such as computer science and engineering. This is an important conversation that is critical to moving the needle in the direction of a more diverse and inclusive workforce. We are also welcoming a vibrant generation of STEM students and professionals who are committed to making the field more inclusive and accessible. Still, we have a long way to go, and we must work together to ensure that we do not exclude anyone who can make a valuable contribution.

Barriers to inclusion manifest in many forms. Bias, microaggressions, exclusion, gendered classroom interactions, and non-diverse curricula are all still present in academia. For instance, the information taught in classes may exclude or misrepresent particular social identities, which is effectively a form of oppression. Think about the scientists and engineers you see in media, and how often your study interests are validated by people that look like you.

I am very proud of our work at the University of Denver. Our inclusive teaching programming portfolio has blossomed and now includes an open-access website that gives information on all the best tools and approaches to teaching inclusively. We have also launched a compulsory online course for faculty that covers the principles of inclusive teaching.

It's important to remember that teaching and learning are sciences in themselves. Everything you learn is filtered through the identities you claim at any given time in your life; being curious about inclusion will expand your understanding of what you need to develop and ultimately succeed.

I am most motivated by leaving the world a little better than I found it. I hope to make way for future generations of scholars who will arrive in education with an understanding of how DEI permeate every aspect of our life. We need to equip ourselves with tools to identify these issues, and work towards a world where collaboration and understanding across differences in identity is embraced.

HOW DID CHRISTINA BECOME AN EXPERT IN ACADEMIC ASSESSMENT?

As a child, I loved asking questions and finding answers in encyclopedias (in the days before the internet)! I read voraciously and especially loved reading stories about people with superpowers, like Roald Dahl's 'Matilda'. I imagined everybody had superpowers that could be unlocked and activated to make the world a better place.

I studied English at university and became an administrator providing career counselling and leadership training for college students. During this time, I stumbled across research articles about assessment. This lightbulb moment led me to pursue a doctorate in education policy, so I can now use assessment as a tool to influence educational systems and policies.

Grit and determination are etched in my genealogical trail. My grandparents escaped North Korea on top of a train, and my mother emigrated to the US to acquire her computer science degree, whilst working two jobs and raising me. My gratitude for my mum is infinite. She taught me the value of hard work, power of education and wisdom of love. I am also grateful for family, friends and colleagues who make the journey much lighter and brighter; it takes a village to cultivate success!

While I love research, I enjoy activities such as yoga, meditation, gardening and spending time with family, friends and my 100-lb dog.

HOW DID VALENTINA BECOME AN EXPERT IN INCLUSION?

In my childhood, I enjoyed playing piano, chasing iguanas and learning languages. I was born in South America and travelled extensively, eventually moving to the US when in middle school. Before then, I had grown up in an area where most people looked like me and shared cultural practices – I only became aware of prejudice and discrimination when I arrived in the US. I developed a keen interest in why these dynamics occurred, which led to my academic career.

My life experiences have truly informed my work. I left my country at a time of political turmoil, and transitioned from prestigious Latin American private schools to a series of North American public schools that radically changed my worldview and challenged my identities. My awakening continued well into my years as an undergraduate and graduate student. I would go on to become a US citizen and receive two bachelor's, a master's, a Ph.D., and professional certificates, while managing the impostor syndrome and racial battle fatigue that stemmed from decades of micro-aggressive stress in invalidating environments. These profound experiences shaped my practice and continue to advance my work. My parents also inspired my career from very early on. My dad was a cardiovascular anaesthesiologist committed to providing excellent medical care to people from disadvantaged socioeconomic backgrounds. My mom has worked with many illustrious organisations, such as NASA. Currently, she spends a lot of time helping under-represented communities have a voice in the politics of our city by providing simultaneous translation.

My success stems from determination, grit and passion for what I do. I also have a love of literature, which I focused on for my doctorate; literature can be like a nation's private diary, providing vivid insights into its inner workings and culture.

My children fill my life with joy and provide great perspective. I have great hope for future generations!

PATHWAY FROM SCHOOL TO SOCIAL SCIENCE

Christina and Valentina emphasise the value of an interdisciplinary skillset, including science and humanities. A career in social science can be approached from many directions, but Christina suggests mathematics and psychology as especially useful subjects to take.

Social science is very broad and can include many other aspects aside from Christina and Valentina's focus areas, such as economics or geography. As Christina's career path indicates, it is sometimes possible to switch from studying humanities to further education in social science.

HOW TO BECOME A SOCIAL SCIENTIST

- According to QS World University Rankings, the best universities to study social sciences are Harvard, London School of Economics, Stanford, Oxford, and Cambridge.
- There are apprenticeships available for jobs that involve social science, such as social work and health care and user-experience research.
- According to salary.com, the average salary for a social scientist in the US will cover a broad range, depending upon their industry. This can include universities, local governments, marketing research firms, think tanks, and non-profit organisations.

DID YOU KNOW THAT GANGS ARE NOT ALL ABOUT CRIME AND VIOLENCE?

WE ARE BOMBARDED BY THE MEDIA WITH ENDLESS NEWS ABOUT GANG VIOLENCE AND CRIMINAL ACTIVITIES. HOWEVER, A GROUP OF SCIENTISTS WANT TO PUT FORWARD A DIFFERENT SCENARIO. **DR CARLES FEIXA PÀMPOLS** AND DR **JOSÉ SÁNCHEZ GARCÍA**, BASED AT **POMPEU FABRA UNIVERSITY** IN BARCELONA, SPAIN, ARE WORKING ON A MULTINATIONAL PROJECT KNOWN AS **TRANSGANG** TO HIGHLIGHT A MORE FAVOURABLE VIEW OF GANG CULTURE. A VIEW WHERE GANGS CAN RESORT TO MEDIATION – AND NOT VIOLENCE – TO SOLVE CONFLICTS

TALK LIKE AN ANTHROPOLOGIST

GANG – informal youth group, typical of urban-popular areas, characterised by its connection to a local territory, a situational leadership, and by the moral solidarity existing among its members. This concept has a criminal facet, a recreational facet and many hybrid expressions

BANDA – the Spanish equivalent for 'gang'

MARA – short for Marabunta, a mara is a form of gang originating from the US, which spread to countries in Central America, including El Salvador, Honduras and Guatemala. Their activities are mostly criminal, such as drug trafficking, auto theft and illegal immigration. Members often have tattoos to show their affiliation to the gang

PANDILLA – street gang present in Spain and Latin America. Sometimes it means simply a group of peers; on other occasions it means a criminal group

CLICAS – cells or groups derived from the original gang. In the 1980s and 1990s, many gang members were deported from the US back to their countries in Central America. Upon arrival, they formed a new gang known as a clica. For example, the US version of the 18th Street Gang became M-18 in El Salvador in 1996 with three clicas

COMBO – slang for street gangs, often used in Colombia

MEDIATION – structured and interactive process to help disputing parties resolve conflict. Crucially, this is done through specialised communication and negotiation techniques. All participants must actively participate in the process

CULTURE – in anthropology, culture does not mean an appreciation of literature or the arts. It refers to people's beliefs, customs and knowledge. These are expressed in many ways, including art, music, dance or even cooking

SOCIAL ANTHROPOLOGY – involves the study of the ways in which people live in different cultural and social settings around the world. Gang culture is one example

What comes to mind when you think of 'gangs'? In many cases, the word 'gang' is used to describe the evils of youth culture, and all the violence and crime associated with a strong street presence. However, young men and women are not born violent gang members. Instead, a history of family breakdown, poor education, unemployment and poverty forces them to join youth street groups.

Similarly, it is often thought that the only way gangs know how to solve a conflict is through violence. Dr Carles Feixa Pàmpols and Dr José Sánchez García, based at Pompeu Fabra University in Barcelona, Spain, want to offer a different explanation, however. They are keen to learn how these groups can use mediation to address their issues internally and with other groups.

City gangs, like in Philadelphia and Chicago, really came to life in the 19th century in the US. Often, these groups were set up to defend the interests of newcomers to the region, such as Irish gangs in the 1880s and the Latino gangs in the 1920s. By the late 1950s, the American gang model reached other parts of the world, mostly through cinema

and television. Across the globe, youth gangs started to develop in Latin America, Europe and even Africa, mostly following the American model but with their own regional traditions.

There is a lot of research into gang culture, but for all these years, the focus has been on criminal activities and violent behaviour. Few people have considered how gangs can have a positive influence. This includes, for example, forming a welcoming place for new members migrating from a different country or being the first on the scene to help the community, such as in 2017 when a massive earthquake hit Mexico. "In short, we need new ways of talking about youth gangs in the global era and this project sets out to fill this gap," explains Carles.

LOOKING FOR POSITIVES

Carles, José and their international team are looking at successful cases of youth gangs and social inclusion. Their TRANSGANG project focuses on Latino and Arab youth gangs from several locations in the Americas, Southern Europe and North Africa, and across different gang cultures, including pandillas, clicas, combos and maras.

Latino and Arab youth populations are increasing in America and Europe. Many young men and women from these groups feel rejected by society and stigmatised with allegations of delinquent behaviours, drug trafficking and radicalisation. "These images are far from the real situation," explain the researchers. "Our aim is to help these populations integrate in society, acknowledging their circumstances and youth culture."

PRACTICAL TIPS TO HELP RESOLVE A DISPUTE

For the researchers, mediation is key. Their ambition is to empower youth street group members through mediation, to give them the confidence and skills to avoid marginalisation. Crucially, mediation is not a magic wand that can solve every conflict; sometimes conflicts do not have a solution that suits both sides, but those involved can learn to handle a conflict situation through mediation.

Interestingly, mediation may come naturally to gang members. Most members are forced to leave school early, but their time in the gang gives them 'hidden skills' like empathy, resilience and first-hand migration experience, which they can share with new members. The TRANSGANG team believes that, "with the proper training, gang members can turn into valuable professional mediators, as demonstrated by former members of youth street groups who now work mediators for NGOs, associations, social services and even private companies". Youth culture – like rap battles – could be another tool for mediation.

Excitingly, Carles and José found that not only have some youth groups embraced TRANSGANG's approach, but they also wanted to become a legal organisation. This is not an easy process, of course, because some of the gangs' members lack trust in the authorities and are therefore reluctant to 'enter' the system.

One youth group, the Almighty Latin King and Queen Nation (or Latin Kings), was willing to talk to resolve conflict, but the regional government in Madrid was in strong opposition. The first principle of mediation – cooperation on both sides – was missing. In Madrid, the Latin Kings are still an illegal gathering. In another region of Spain, however, the Latin Kings were successful in becoming recognised as a legally-accepted, cultural association. This is thanks to successful mediation between the local government and the Latin Kings in Barcelona.

CHANGING PEOPLE'S MINDS ABOUT GANGS

The researchers working on the TRANSGANG project are keen to change the public's perception about youth street groups. In addition to academic publications, the project will produce three documentary films and set up public events, with the participation of current and former members of youth gangs.

What is more, the Spanish leading newspaper *El País* is publishing a series of articles on gang culture and the TRANSGANG project. These articles focus on the positive aspects of youth street groups. "If we keep that community alive after the completion of the project, we will have succeeded," says José. "We believe that the lack of mediating spaes and communication is one of the fundamental problems of global societies."

What is clear is that gangs themselves are not the problem. Indeed, they can be active agents in the search for solutions. Young people, especially those from a deprived background or another country, join these groups for solidarity and as a part of growing up. If gangs are formed under strong moral codes of conduct and rely on mediation rather than violence to solve their conflicts, these groups can be a very positive force in society. In this scenario, senior members are ideally placed to support newcomers and steer them into responsible adulthood.

DR CARLES FEIXA PÀMPOLS

Principal Investigator

DR JOSÉ SÁNCHEZ GARCÍA

Scientific Coordinator

Department of Communication
Pompeu Fabra University
Barcelona, Spain

FIELD OF RESEARCH

Anthropology

RESEARCH PROJECT

Transnational Gangs as Agents of Mediation: Experiences of Conflict Resolution in Street Youth Organisations in Southern Europe, North Africa and the Americas (TRANSGANG)

FUNDER

European Research Council

ABOUT ANTHROPOLOGY

In very general terms, anthropologists ask questions about people, their culture and environment. A popular misconception is that anthropologists only study remote tribes. While this is true for some researchers, many others – like Carles, José and Eduard (see page 4) – carry out their work in a city environment and seek to understand how people behave in different, everyday scenarios. The TRANSGANG project looks at ways to resolve conflicts within gangs, between gangs, and between gangs and their social environment.

WHAT DOES 'SOCIAL ENVIRONMENT' MEAN?

Social environment refers to the immediate social setting in which people live. It includes the culture that an individual is educated or lives in, and the people and institutions with whom they interact. It includes informal and formal rules, as well as values, feelings, thoughts and actions, which determine the actual position of a person in a given setting (e.g. workplace, school, family).

WHY STUDY ANTHROPOLOGY?

Anthropology is more necessary than ever. In a world where inequalities seem to be growing, having the tools to allow us to study, understand and combat them is important. Also, as Carles explains, "anthropology gives you tools to be a better person and develop true empathy towards others. As an anthropologist, you can improve your critical thinking, respect for cultural diversity and set up development projects to help people".

HOW TO BECOME AN ANTHROPOLOGIST

- If you are interested in people, human behaviour, culture and social relationships, anthropology may be the subject for you.
- Anthropology gives you skills that can be applied in different environments, such as problem solving, communication, presentation and reasoning – all of which are highly valued by employers.
- Possible jobs include university lecturer, social worker, conservation officer, archaeologist, museum worker, public health coordinator, charity worker, to name just a few.
- According to Salary Expert, an experienced anthropologist can expect to earn 40,000 Euros **(https://www.salaryexpert.com/salary/job/anthropologist/spain)**

PATHWAY FROM SCHOOL TO ANTHROPOLOGIST

Carles and José recommend studying social sciences or humanities such as geography, history, sociology and psychology.

At degree level, anthropology, social anthropology or biological anthropology are good options. Many honours courses combine other social sciences or vocational subjects such as law: **https://www.topuniversities.com/courses/anthropology/guide**

Many courses have the option to study abroad for a year. This is the best way to develop your understanding of anthropology across the world.

BREAKING THE CYCLE OF CRIME

Our perception of gangs is often negative, but there are many positive stories – stories of rehabilitation and community integration. The best way to break the cycle of crime is to turn those difficult and traumatic experiences into forces for good.

As an example, Carlos Cruz, a former gang member, started Cauce Ciudadano to offer opportunities to other gang members living in environments marked by social exclusion, drug trafficking and criminal activities. You can read more about his and other members' experiences here: **https://www.facebook.com/CauceAC/**

The Ensemble LiberARTE from El Salvador is a string orchestra composed of young women who are either living or have lived at the ISNA Prison for Young Women. The Asociación Tiempos Nuevos Teatro is working with these women to increase their self-esteem and skills. You can read more about their work, both with former gang members and women in prison or living on the streets, at: **http://www.tnt.org.sv/wp/casa-de-encuentro/que-es-cde/.**

César Andrade Arteaga was 18 and considered a minor when he joined the Almighty Latin Kings and Queens Nation (or Latin Kings). Over the years, he acquired Latin Kings tattoos.

Tattoos of César's 'family' - the Latin Kings.

AN ETHICAL DILEMMA

Researchers on the TRANSGANG project have to follow a strict code of ethics. They are studying members of youth street gangs, many of whom may be teenagers and therefore considered minors. Carles, José and the TRANSGANG team have to ask themselves a lot of ethical questions. For example, only teenagers aged 14 and over were invited to take part in the project, but are 14-year-olds experienced enough to understand what it means to be involved? Do their parents or legal guardians need to be informed? What if by telling parents or legal guardians, the child is at risk from harm? If a gang member admits to taking part in a criminal activity, should the police be informed?

What do you think?

MEET DR EDUARD BALLESTE, AN ANTHROPOLOGIST WORKING ON THE TRANSGANG PROJECT IN BARCELONA

WHAT DID YOU WANT TO BE WHEN YOU WERE YOUNGER?

I was not sure what I wanted to be. It was difficult to imagine a trade or a career to which I would like to dedicate myself. Even so, I have always liked everything related to history (movies, books, museums, etc.).

HOW DID YOU END UP STUDYING SOCIAL ANTHROPOLOGY? WHAT DREW YOU TO THIS SUBJECT?

It was a mix between chance and opportunities that opened up. I like the search to understand meanings, cultures and worlds that, although geographically close, could be unknown to me. Finally, fate gave rise to an opportunity (both economic and academic infrastructure) to do a PhD in social anthropology and be able to fully enter this field.

WHAT IS YOUR ROLE IN THE TRANSGANG PROJECT?

In the TRANSGANG Project, I have the role of local researcher for the city of Barcelona (the Core Case of Southern Europe). I oversee fieldwork in the city and coordinate other researchers involved.

WHY ARE PROJECTS LIKE TRANSGANG IMPORTANT?

It focusses on people who normally are invisible or stigmatised. It not only makes them visible from an external position, but also tries to give them a voice. They can narrate their situations and their history. This makes it possible to deepen our understanding of these groups in a way that is separate from the mainstream discourse of the media or the politicians themselves.

I think it is great to carry out a comparative study between 12 cities in three different geographical regions. Such commitment can not only provide valuable knowledge about the groups of young people themselves, but also delve into the impact of migration.

WHAT CAN YOUNG PEOPLE WHO ARE NOT GANG MEMBERS LEARN FROM THIS PROJECT?

I think that the project itself goes beyond gang members. Understanding the experience of living in the margins of society, whether through gangs or other groups, allows us to understand how exclusion and stigmatisation affect specific groups.

CAN GANGS TEACH US ABOUT EMPATHY, RESPECT AND SOLIDARITY?

CÉSAR ANDRADE ARTEAGA, A MEMBER OF THE LATIN KINGS GANG, WORKS WITH A UNIQUE RESEARCH PROJECT CALLED **TRANSGANG**, WHICH AIMS TO UNDERSTAND AND PROPAGATE THE POSITIVES OF GANG CULTURE AND MEDIATION. NOW AN ASSISTANT RESEARCHER, CÉSAR TELLS US HOW HIS EXPERIENCE CAN TEACH US TO WORK TOGETHER TO HELP OTHERS

YOU BECAME A MEMBER OF THE ALMIGHTY LATIN KINGS AND QUEENS NATION (A.K.A LATIN KINGS OR LK) WHEN YOU WERE 18 YEARS OLD. HOW DID YOU END UP JOINING THE GANG?

I joined the LK in February 1994, even though I was a minor. If I think of any reason for joining, it is that I wanted to gain respect on the streets and from the people in my neighbourhood. Another reason for joining was to try to end other youth gangs so that the LK was the only one left in the neighbourhood and in the city of Portoviejo in Manabí [a province in Ecuador]. We also wanted to be like Robin Hood – taking things from those who had the most to give to those who had very little.

We managed to clean the poorest neighbourhoods of delinquents, do social work with other young people, create respect for our members, emblem and our name, and prevent other groups from growing. I became recognised. But I must admit, achieving this involved having to cry over the loss of many good warriors.

FOR YOU, AS A YOUNG ECUADORIAN MALE, WHAT WERE THE BENEFITS OF JOINING THE LK?

The biggest benefit was gaining respect on the streets, without forgetting the values that my parents and the LK taught me. It allowed me to become a leader, forge an identity and raise my self-esteem. I felt the LK was good for something. The gang re-educated me about values such as internal and external respect, brotherhood, solidarity, love for all the different colours of gang members and, if necessary, to die for our brothers, LK crown and Nation. Sometimes, there were violent confrontations with other gangs.

YOU MOVED TO MADRID, SPAIN, IN 2003. WHAT WERE YOUR REASONS FOR LEAVING ECUADOR AND THE LK?

Despite migrating to Spain, I have never stopped being a member of the LK. When you are part of the gang, you do not leave it until your heart stops beating. Little brothers and sisters will remember you forever, because every month your name is shouted up at heaven in recognition of your love, effort and sacrifice. You can walk away, but you will never stop being part of the family.

I travelled to Spain because, like any other migrant, I was looking for a better future for myself and my family. Conflict in the Santo Domingo de los Tsachilas province in Ecuador between gangs and with the police was getting worse, which was another reason to migrate. On arriving in Spain, members of the LK contacted me to expand our network there and so I became the leader of this network – but with another mindset. I wanted to help young people from the underworld so that they didn't make the same mistakes that I made in the past.

WHAT IS YOUR ROLE IN THE TRANSGANG PROJECT?

I work as a research assistant and facilitate contacts with members of different Latino groups nationally and internationally. I organise mediation workshops, such as the current music production project called The Royal Life: The new King. Involving active and non-active LK members, we compose hip-hop

The TRANSGANG project is led by Dr Carles Feixa Pàmpols at Pompeu Fabra University, Spain. Its aim is to understand the positives of gang culture and how to resolve conflict through mediation rather than violence. To learn more, visit:

https://www.upf.edu/web/transgang/project

and rap songs related to our life events. It is a mediation project that works with young migrants from Barcelona. We have already produced three songs and a video of a fourth song is about to come out, which we will publish on our YouTube channel.

I organise the TRANSGANG project library, which involves collecting press releases, transcribing interviews and documenting the project. I'm also the webmaster of a blog about a book called El Rey (The King), published together with Dr Carles Feixa Pàmpols, the principal investigator on the TRANSGANG project.

I have known Carles since 2005 and have collaborated with him on various projects, as an informant. The TRANSGANG project gave me the opportunity to work as a research assistant.

WHY IS THE TRANSGANG PROJECT IMPORTANT TO YOU PROFESSIONALLY AND PERSONALLY?

From a professional point of view, the project has allowed me to enter the world of social research and learn about techniques and methods that will open doors for me when this project has ended. My computer skills and knowledge have advanced a lot and I'm discovering other youth gangs, which I didn't know about previously. I'm also learning about how mediation works. All of this is a great professional leap for me.

From a personal point of view, I'm meeting professionals with a huge amount of knowledge and human values, who make me a better person every day. Thanks to the TRANSGANG collaboration, I've been able to obtain Spanish residency and citizenship. This allows me to stabilise my life, not fall prey to temptations, and to look to the future with optimism.

HOW HAS YOUR EXPERIENCE WITH THE LK SHAPED YOU?

Indirectly, LK was already mediating between Latino youth gangs as well as organising cultural and sporting events, and this has given me relevant experience to work on the TRANSGANG project. I also learned leadership skills and to apply the values that represent LK as a group: love, honour, obedience, sacrifice and righteousness – five sacred points of the LK crown.

WHAT POSITIVE ATTRIBUTES DOES YOUR EXPERIENCE BRING TO SOCIETY?

Having experienced some dramatic things in my country, Ecuador, my life experience serves as an example to other young gang members so that they don't fall into violent attitudes and can become better people. Furthermore, gang values, in our current world, can serve as a model to show that human relationships can be different; they can be based on empathy, solidarity and mutual respect.

The El Grito gang meet at the Monserrat Monastery near Barcelona in Spain, in respect and love for the brothers, sisters, princes and princesses who came before them.

WHAT ADVICE DO YOU HAVE FOR YOUNG PEOPLE WHO ARE GANG MEMBERS?

I would never ask you to leave your gang because it is a family for you, a feeling you carry inside. What I would ask is that you don't commit violent or criminal acts; on the contrary, I'd ask that you work together to help others see that this path leads nowhere.

WHAT CAN YOUNG PEOPLE WHO AREN'T GANG MEMBERS LEARN FROM THE TRANSGANG PROJECT?

You can learn about the true motivations behind belonging to a gang – the reasons why gang members want to belong and that it is about seeking help in different way. You'll learn about our identity, our history, our values, which have been violent at times in the past, but are actually about benefiting everyone and living harmoniously. We are not violent people, so we can try to end the negative labels that everyone puts on us. This is the most important thing: to teach young people about who we really are and what we truly stand for.

HOW TO USE OUR EDUCATION AND CAREER RESOURCES

Go online and you'll find loads of research articles, and all related to different fields. Whether you download the PDF or read the article online, you'll find that each research article contains all the information you need to help you learn more about STEAMM (science, tech, engineering, arts, maths, medicine).

www.futurumcareers.com/articles

Got a question for the researcher? Send them an email: info@futurumcareers.com. Or write a question/comment in their comments box at the bottom of their article online.

Read about fascinating research projects that are happening right now

Put yourselves in the shoes of the researcher and learn key words relating to their work

Imagine how the research affects the world around you

Find a short summary of the research project in our researcher profiles

Explore new fields of research and study, and learn about different career options

Discover opportunities that are open to you in different fields (apprenticeships, internships, courses) and find out how much money you can earn

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

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

Get top tips from scientists and researchers

Find out which courses to take at school, college and university

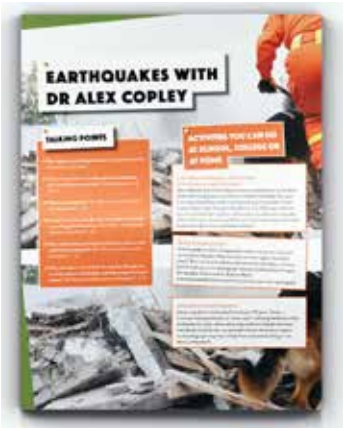
ACTIVITY SHEETS

Go online and you'll find activity sheets for all of our featured articles: www.futurumcareers.com/resources

See if you can answer questions about the research in the article

These questions are linked to Bloom's Taxonomy to help you remember, understand, apply, analyse, evaluate and create!

https://www.bloomstaxonomy.net



Try out activities you can do in school, college or at home

Get links to even more awesome resources

KEEP IN TOUCH!

We hope you've enjoyed reading Futurum. Did you know that all of our articles and accompanying activity sheets are available online?

Check out our website: **www.futurumcareers.com**

We publish new articles and activity sheets all the time. Keep yourself up to date by signing up to our monthly newsletter: **www.futurumcareers.com/sign-up**

Or follow us on social media for instant updates on new articles, blogs and events:

@FUTURUMCareers

@Futurumcareers

@Futurumcareers

Futurum Careers

CONTACT THE RESEARCHERS IN THESE ARTICLES!

Got a question about the topics in these articles? Or a broader, scientific question about the world around you? You can ask our researchers in six easy steps:

1) Go to www.futurumcareers.com/articles

2) Select the article you want

3) Scroll to the bottom

4) Write your question in the comments field

5) Click 'Notify me of follow-up comments via email'

6) Click 'Submit Comment'

The researcher will get back to you with their answer. Scientists are busy people, though, so expect an answer in a few days' time!

TELL US WHAT YOU THINK

We would LOVE to hear from you: send us a message through social media, comment on our articles or blogs, or send us an email: info@futurumcareers.com

We'll get back to you!

THE 2021 STEM DISCOVERY CAMPAIGN

Join the 2021 STEM Discovery Campaign, an international initiative organised by Scientix that invites projects, organisations, libraries, schools, universities and youth clubs across Europe and around the world, to **celebrate careers and studies in the fields of Science, Technology, Engineering and Mathematics (STEM)**!

The tagline for this year's campaign is:

SUSTAINABILITY AND CITIZENSHIP

We believe it's the **time to take action** and encourage every stakeholder involved in education to organise activities that will increase students' awareness about these topics, highlighting relevant skills that students will need in the near future.

Running from **the 1st of February 2021 until the end of April 2021** with a peak of activities during the week of 23-30th April, the STEM Discovery Campaign is a celebration of the ongoing commitment and work carried out by dedicated teachers and any every stakeholder in education to improve science education and literacy in Europe.

We encourage everyone to get involved in the 2021 STEM Discovery Campaign by organising STEM activities and featuring them on the STEM Discovery Campaign map! **Here are some ideas of what you can do to contribute to one of the biggest STEM campaigns worldwide:**

- Organise any (online) STEM activity with/for your students, such as webinars, chats, discussion boards, quizzes etc.
- Participate in one of our STEM competitions (see the "Competitions" section on our website)
- Use the Scientix Moodle to create your own online courses
- Use the Scientix Online Meeting Room to host your own webinars, live events, Q&A etc.
- Participate in one of our online events (see the "Other opportunities" section on our website)
- Write a story of implementation on the STEM Discovery Campaign Blog
- For schools, projects and organisations: become an official partner of the 2021 STEM Discovery Campaign

JOIN US AT HTTP://BIT.LY/SDC21

European Schoolnet
SCIENTIX

The STEM Discovery Campaign has been funded under the European Union's H2020 research and innovation programme – project Scientix 4, coordinated by European Schoolnet (EUN). The content of the document is the sole responsibility of the organizer and it does not represent the opinion of the European Commission (EC), and the EC is not responsible for any use that might be made of information contained.