Scientia

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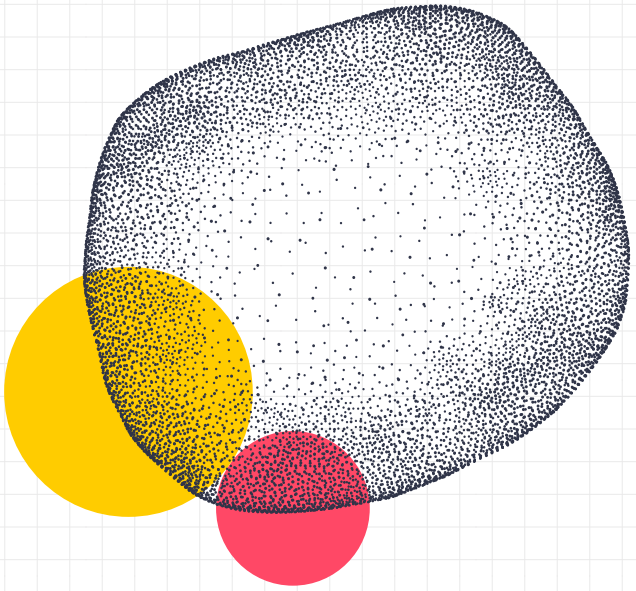

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WELCOME...

Welcome to the latest issue of Scientia! This instalment showcases recent advances in discovery, research and innovation across a fascinating breadth of disciplines. Whilst great achievements by humanity throughout history have led to happier, healthier, and longer lives for many, we still face huge challenges in our modern age. Climate change, diseases that remain without a cure, social injustice and poverty are some of the urgent global problems researchers are tackling in this important issue.

Our first section focuses on the Earth and the environment. Here, we can read about recent insights into how modern human activities are affecting our planet and, critically, how we might mitigate these negative consequences. From recreating rocky reefs to restore marine populations to developing viable alternatives to fossil fuels, the inspired efforts of researchers to protect our precious planet may offer a case for cautious (but not complacent) optimism about the future of climate change.

The second section delves into exciting advances in physical science, engineering and technology and the vastly diverse applications of these. We can read about how vehicle-to-everything communication is fast becoming a reality, and how future spacecraft may benefit from design innovations to improve manoeuvrability in planetary orbits. We can also read about the intriguing mysteries of supermassive black holes, and theoretical developments in physics that are challenging conventional thinking.

Section three is dedicated to health and medicine, including progress in understanding and treating cancer, cardiovascular disease, severe infections, and other potentially devasting and fatal conditions. We can also read about novel family-centred approaches to neonatal intensive care and how complex data are presented impacts behaviour change relating to the spread of COVID-19.

In section four, we celebrate innovation in training and development. Here, we can read about how different disciplines are inspiring the next generations of researchers. From fostering entrepreneurship in medicine to educating and training a new cohort of cybersecurity technicians, there is a clear emphasis on widening participation and promoting inclusivity and diversity.

In section five, we turn to psychology and neuroscience and explore the latest insights into human and animal consciousness, learning and memory, and well-being. We can read about the dark side of morality, how the COVID-19 pandemic has led to increased levels of health anxiety and safety behaviours, and how research has driven a new science of animal culture, conservation and welfare.

Our final section provides a riveting exploration of new knowledge and insights across the social sciences and humanities, spanning topics including business, economics, sociology and history. From the consequences of child labour in the current day to the ancient Nok society in Western Africa, we meet the researchers helping us to more fully understand the world, past, present and future.

MEET THE TEAM

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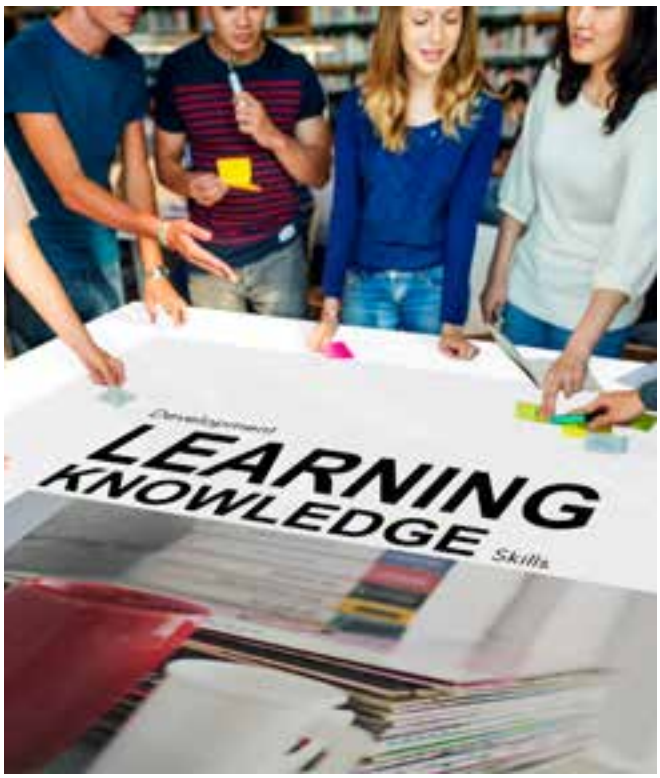

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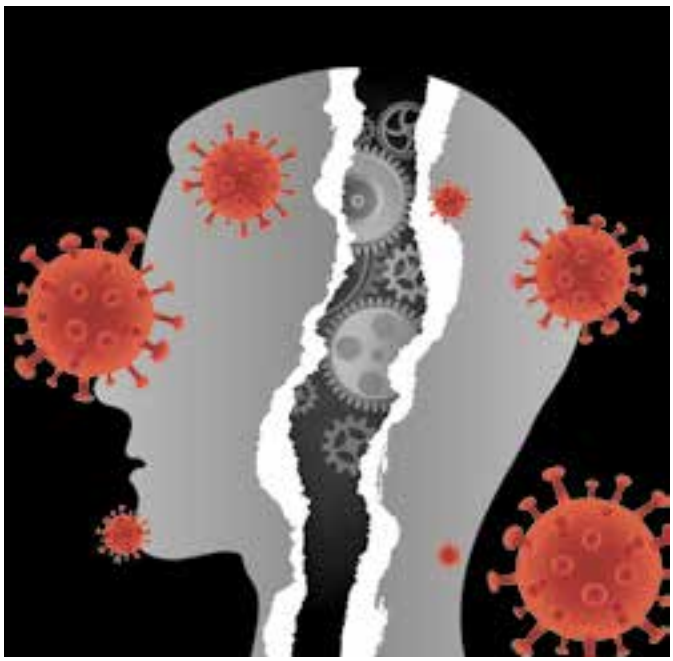

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EARTH & ENVIRONMENT

SUNSHINE AND ORGANIC MOLECULES IN WATER

Organic molecules dissolved in rivers, lakes, seas and oceans are essential to plant and animal life. Some of these molecules are also degraded and enter a complex cycle of carbon, nitrogen and sulphur containing compounds. Surprisingly, scientists currently have a limited understanding of the fate of these molecules. **Dr Daisuke Minakata** and his colleagues from Michigan Technological University are involved in an ambitious programme to overcome this critical knowledge gap.

Organic Molecules in Water

Organic molecules are complex carbon containing structures that are indispensable for the existence of life. 'Organic material' is an umbrella term that includes a very wide range of compounds and amino acids – the building blocks of proteins – represent some of the most precious compounds necessary for living organisms. Given the importance of these molecules, it is hardly surprising that NASA is looking for amino acids in the search for evidence of life elsewhere in the universe.

Amino acids and other organic compounds enter natural bodies of water from multiple sources. Bacteria, algae, plants and animals living in the water itself release significant amounts of organic molecules. In addition, agricultural, human and animal waste products also enter waterways in large quantities, contributing to their amino acid and other organic material content.

A Poorly Understood Cycle

The fate of these compounds present in fresh and saltwater environments is poorly understood. Some organic molecules, including amino acids, are taken up and reused by organisms living in the water, but a significant proportion is broken down through chemical and physical processes and these smaller degradation products enter a complex cycle of nitrogen and sulphur containing molecules. The photochemical process is one important degradation pathway … and this is where things get complicated.

Theoretically, the energy from sunshine could degrade certain amino acids, making them unavailable for living creatures. However, there is evidence that dissolved organic molecules generate very short-lived reactive intermediates under sunlight irradiation and these reactive intermediates degrade the amino acids – the photosensitising effect of dissolved organic molecules.

Dr Daisuke Minakata from Michigan Technological University was prompted to develop a theory to explain the loss of critical amino acids from water. He assumed that other organic molecules absorb the energy carried by the rays of sunshine and those reactive intermediates transform amino acids into small pieces. According to his theory, such light-activated compounds could act as catalysts, inducing the indirect breakdown of critical amino acids.

A Need to Simplify Things

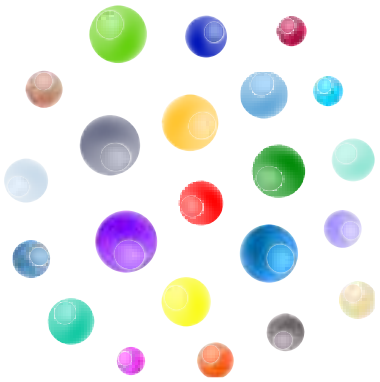
As Dr Minakata explains, testing this theory was difficult for two reasons. Firstly, dissolved organic molecules form very poorly defined, large complexes that show considerable variability at different locations. Using such complex mixtures in experiments would make the analysis of the results extremely difficult. The other issue was that are more than 20 different amino acids in nature, and these are very different chemically. Finding the degradation products of all of these would be a Herculean task. Thus, to conduct the experiments, the research team needed to simplify things.

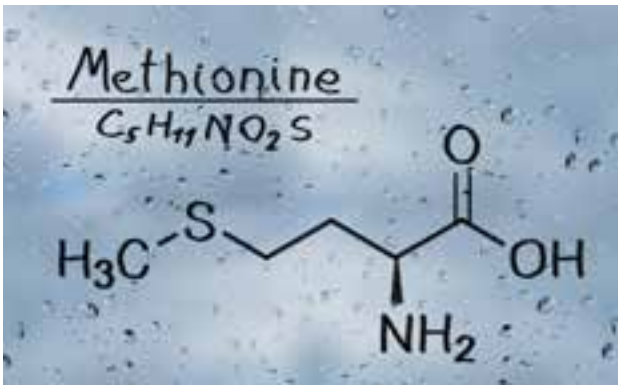
Despite the complexity of the dissolved organic material, scientists had identified the three main mechanisms explaining its catalytic behaviour. Furthermore, they were able to identify smaller single compounds that could mimic this action. Using these mimics in the experiments promised to simplify the analysis of the results.

The next decision Dr Minakata and his colleagues made was that they would initially focus their attention on the study of a single amino acid, methionine, that is typically depleted in water under natural conditions. Methionine is one of only five photochemically degradable amino acids and it contains sulfur-atom, a unique element that contributes to the global cycling of sulfur. Sulfur cycling is not as well understood as carbon and nitrogen cycling.

An Elaborate Experimental Setup

Next, the scientists needed to build the appropriate experimental setup. Firstly, the effects of sunlight were replicated using a high-energy xenon arc light





source. The water, containing the mixture of methionine and the tested catalytic mimics, needed to be placed under this light in a container that allowed all the wavelength through. However, illuminating a relatively small volume of solution in the specialised quartz containers resulted in an additional problem: the water became very hot. Thus, scientists had no way of establishing which degradation products were produced by light exposure, and which ones resulted from the heat. Understanding the basic science needed a controlled environment in the laboratory as the first step. This meant they needed to build a cooling system that allowed the team to keep the solution at the desired temperature.

A technique called mass spectrometry was used to detect individual degradation products. After irradiating the samples with the artificial sun, the molecules were exposed to a strong electric field that made them fly along a vacuum tube. Since under these conditions smaller molecules accelerate faster while larger ones move more slowly, measuring the time it takes for a molecule to reach the detector allows its mass to be determined. This allowed the scientists to establish what its chemical structure was likely to be. This may sound complicated – and it certainly was. The group had to resort to the use of some of the most cutting-edge equipment to make these measurements.

The Results Start Coming In

The initial screening experiments identified common methionine degradation products, and a range of compounds that were produced in smaller quantities during light exposure in the presence of mimics acting as catalysts. Knowing the composition of these degradation products allowed the scientists to work out the possible chemical reactions resulting in their emergence. Once the reaction pathways were identified in this relatively simple experimental system, the scientists started to aim higher. Instead of using chemical mimics acting as catalysts, they started to use a more complex naturally occurring dissolved organic molecule mixture, derived from either the Suwannee River or an Elliot Soil sample, typically used as standard organic molecules.

While these mixtures have the same technical name, humic acid, this is a misleading scientific term, as humic acid represents a very complex mixture of decomposed biological material, that is different at the two sites. Not unexpectedly, the degradation of methionine produced in the presence of the two distinct humic acid samples showed marked differences. Firstly, the light-dependent degradation of methionine was faster, particularly in the presence of the Elliot Soil humic acid. The proportion of produced degradation products also showed considerable differences, both between the two humic acid samples, and compared to the results obtained using simple chemical catalytic mimics. However, the results from simple mimics advance scientific understanding of the roles of different sites in complex mixtures of dissolved organic compounds.

Computational Chemistry to the Rescue

As Dr Minakata tells us, testing the mechanisms causing the degradation of the amino acid caused by such complex chemical mixtures is impossible using conventional experimental approaches. In the analysis of such complex reactions, scientists are increasingly relying on the use of computational chemistry.

By the start of the 21st century, scientists had accumulated enough experimental information to enable them to model chemical reactions using computers. By modelling details such as the shape of molecules, their known interactions, the energy needed to introduce changes, or the amount of energy being released during chemical reactions, scientists can predict chemical interactions, including those that have not been studied under experimental conditions.

After entering their experimental data into computer models, Dr Minikata and his colleagues were able to take advantage of this approach to fully understand the fate of methionine in natural water. To a superficial observer, this may sound like a lot of effort to study the fate of a single amino acid. However, deciphering what happens to this vital building block provides is the first step in understanding chemical processes in nature that allow life to flourish in natural bodies of water. Unquestionably, such an understanding is fundamentally important to humanity.

Meet the researcher

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Dr Daisuke Minakata obtained his BSc degree at the Environmental Engineering Department of Kyoto University in 2002. In 2005, he completed his MSc degree at the same institution. After moving to the USA, Dr Minakata studied at the Department of Environmental Engineering of the Georgia Institute of Technology, gaining his PhD in 2010. After graduation, he started working as a Research Engineer at the Brook Byers Institute for Sustainable Systems at the Georgia Institute of Technology. In 2013, he was appointed as an Assistant Professor in the Department of Civil and Environmental Engineering at the Michigan Technological University, where he became an Associate Professor in 2019. He also spent a year as a visiting scholar in Europe, at the Swiss Federal Institute of Aquatic Science and Technology in Dübendorf. Over his career to date, Dr Minakata has mentored over 30 graduate students, published more than 50 peer-reviewed papers, and given more than 25 invited and keynote talks and 70 conference presentations. Dr Minakata has been involved in projects exceeding $7M of which his own fraction is greater than $1.3M. His contributions to environmental science have been recognised with several prestigious awards.

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FUNDING

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CADDISFLIES AND THE HEALTH OF FRESHWATER ECOSYSTEMS

Caddisflies are an order of insect species that live in and around fresh water, and are a great indicator of the health of the ecosystem they're in. However, we need a better understanding of their life cycles, their role in the ecosystem, and how the population changes across multiple generations as they hatch from eggs into larvae, grow and moult, and form pupae before their adult stage. **Dr Richard Marchant** at Australia's Museums Victoria has undertaken an extensive 5-year research program to do just that.

Understanding Population Dynamics

Freshwater insects are a crucial part of many ecosystems but detailed knowledge of how populations fluctuate in numbers has seldom been considered in the published research. Dr Richard Marchant at Australia's largest public museum organisation, Museums Victoria, has been addressing this gap in the literature by studying the long-term population dynamics of two species of caddisfly, *Tasimia palpata* and *Agapetus kimminsi*, in the Cumberland River in south-western Victoria, Australia.

Caddisflies are insects of the order Trichoptera, meaning 'hairy-winged', due to the adults having moth-like bristled wings. Indeed, caddisflies are more closely related to butterflies and moths than to so-called 'true flies'. They have a unique life cycle, which has stages both above and below the water. This means they're a great indicator of the overall health of a freshwater ecosystem, but it also means that understanding caddisfly populations requires dedicated and long-term study to successfully track the eggs, larvae, pupa, and adult caddisflies over the span of several generations.

Dr Marchant is especially interested in density-dependent processes in controlling the fluctuations of populations. For example, some dynamics depend only on the total number of caddisflies in an ecosystem, but some, such as resource competition, depend more strongly on their density: how many caddisflies are in each square metre of river? How does their density affect egg-laying? How dense can populations be before recruitment to the next generation is reduced as a result?

Dr Marchant explains that he wanted to find out which life history phases were density dependent. More specifically, he reasons, that if direct density dependence occurs, mortality during a phase of the life cycle should be positively correlated with the density of individuals entering that phase. In other words, if one phase strongly depends on density, we should see a clear negative relationship between the success of individuals in that phase and the density of individuals at the beginning of that phase.

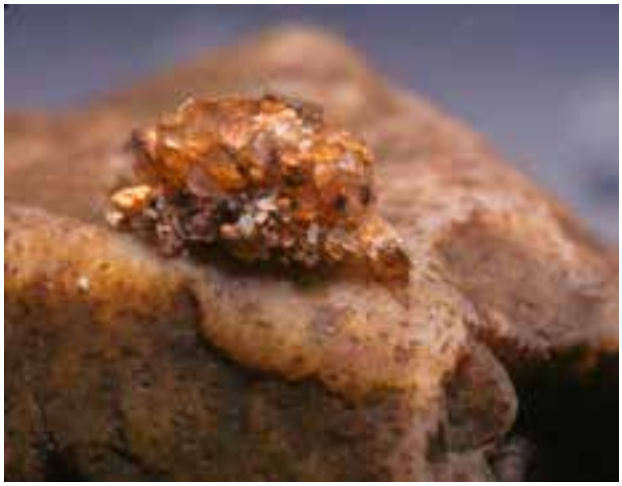
Tasimia palpata larva.
Credit: Dr Julian Finn / Museums Victoria

The Unique Life Cycle of Caddisflies

Caddisflies go through several distinct phases in their life cycle, so understanding how the population changes over time is critical. Although one of the two species has been studied previously, *Tasimia palpata* had not, so Dr Marchant undertook an 18-month preliminary study at the river. This revealed the species was bivoltine, meaning two generations are produced each year – one in winter and one in summer.

The larvae are aquatic and have gills. The adults lay eggs in clumps or masses below the water surface, often underneath rocks, which presumably offers some protection against

Dr Richard Marchant at Cumberland River. Credit Rodney Start / Museums Victoria



Agapetus kimminsi larva. Credit: John Gooderham and Edward Tsyrlin / The Water Bug Book

predation. Once hatched, different species behave quite differently. Most are collector-gatherers, grabbing fragments of detritus and organic matter that float in the water. Some other species sieve the water using silken nets. The two species in this study feed predominantly on benthic algae, photosynthesising microbes which grow on the surface of rocks.

Another unique aspect of caddisfly larvae is that they build their own homes: these are called 'cases' and are tubular structures formed from silk and reinforced with species-specific additions such as sand, bark, sticks, leaves, seeds and shells. These cases are open at both ends, and the larva adds to the case at one end and turns round and trims the rear. To keep oxygenated water flowing through the case, the larva moves around, and the less oxygen in the water the more active the larva must be. This means caddisfly larvae can live in water that's too oxygen-poor for other species like stoneflies or mayflies.

This means that the presence of caddisflies when stoneflies and mayflies are absent can tell us that the freshwater ecosystem is low on oxygen, but not critically low. As well as an indicator of pollution-free water, caddisflies are an important part of the food web, as both larvae and adults are a popular food source for fish, especially newly hatched adults which must clamber out of the water and dry their wings before they can fly.

Studying the population dynamics of large organisms requires years of tracking, but insects go through generations remarkably quickly. Thus, Dr Marchant was able to study ten consecutive generations over 5 years, taking 21 samples each month from April 2004 to March 2009. These were sampled from a 190-metre-long section of the Cumberland River in south-western Victoria, Australia.

Dr Marchant studied the density of the population at specific stages to identify trends. For example, the number of caddisflies

Tasimia palpata (adult male). Credit Dr Julian Finn/Museums Victoria

per square meter at the start of a generation represented the density of larval recruits, while the density when pupa were common represented the density at the end of a generation. Finally, the density of eggs laid by each generation was determined from pupal densities, the development time of pupae, and egg numbers per female.

Mathematical Modeling of Population Dynamics

Since insect populations follow regular cycles, their dynamics can be modelled using relatively simple mathematical tools. In his paper, Dr Marchant analysed the data he collected using a Ricker stock-recruitment curve. This is a model used to predict how many new individuals are born, mature, or immigrate (recruited) in each generation based on the numbers in the previous generation (stock).
Interestingly, this curve was an excellent fit for the larval recruitment of one of the studied species but not the other. The recruitment of *Tasimia palpata* matched the model nearly perfectly, but that of *Agapetus kimminsi* deviated significantly from the model, suggesting other mechanisms are at play in their population.

Further, both species displayed strong density dependence but in different manners. *Tasimia palpata* showed much higher density-dependent mortality during pupation and recruitment, meaning that the population dynamics were more strongly determined by the reproductive phases of the cycle. In contrast, *Agapetus kimminsi* only showed density-dependent mortality

Counting caddis larvae using a viewing tube.
Credit Peter Lillywhite / Museums Victoria

during the larval phase, which was independent of the fluctuations in the density of eggs. In both cases, these density effects were direct, meaning they relied most on the density of individuals at the start of that life phase, and much less on the phases before that (which would imply a delayed or indirect relationship).

Crucially, these findings confirm Dr Marchant's argument that long-term study is necessary to properly understand the population dynamics of these caddisfly species. His research provides a critical new insight into their ecology emphasizing the vital role of density-dependent regulating factors in their life cycles.

Meet the researcher

Dr Richard Marchant
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Dr Richard Marchant studies the ecology of aquatic insects and other invertebrates inhabiting rivers, particularly their species composition, diversity and population dynamics. He began his research career almost 50 years ago by studying the dynamics of brine shrimp populations in salt lakes in Western Victoria, Australia. He then spent several years investigating the feeding and population ecology of riverine amphipods in Ontario, Canada and the composition of tropical invertebrates in billabongs in Kakadu National Park, part of the Northern Territory. Since arriving at the Museum of Victoria 40 years ago, he has conducted much fieldwork on stream invertebrate communities in Victoria and Southern New South Wales, and has examined the stream invertebrates of the isolated sub-Antarctic island, Macquarie. He is the editor of the Memoirs of Museum Victoria, the museum's scientific journal, and is an associate editor of Marine and Freshwater Research.

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FURTHER READING

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MELBOURNE MUSEUM

RECREATING ROCKY REEFS TO RESTORE MARINE POPULATIONS

Much research has focused on Single Large or Several Small ('SLOSS') habitats for the preservation and restoration of biodiversity. Many studies have been carried out in terrestrial environments but far fewer have looked at marine systems. However, it is unwise to make conclusions about the marine environment based on studies carried out on land. Together with colleagues, **Dr Tim Wilms** from the Technical University of Denmark is recreating lost rocky reef habitats and surveying these sites to see how they impact the return of vital marine species to the area.

The restored reefs were monitored using remote underwater video systems, a non-invasive method to survey biodiversity and the abundance of marine organisms.

Geogenic Reef Ecosystems

When we think of healthy and thriving marine communities, we tend to envisage colourful coral-rich reefs teeming with shoals of fish and sea creatures. Geogenic reefs – their non-biological counterparts – play an equally important role in marine ecosystems but are considerably less well-known and understood. Made up of boulders or smaller rocks protruding from an otherwise smooth, soft-substrate seafloor, geogenic reefs provide an important hard surface for the initial settling of algae and larvae that would otherwise be carried past by water currents.

The settlement and growth of algae and sessile immobile creatures such as bivalve molluscs provide a source of food which attracts fish and other sea creatures. Structures in and around the rocks such as holes, ledges and crevices provide shelter in which numerous mobile marine creatures and fishes may flourish and grow. This attracts larger predators from afar, and thus, a functioning geogenic reef ecosystem is born.

The Baltic Sea

Formed by glacial erosion over the past few ice ages, one of the world's largest inland brackish seas – the Baltic Sea – is a north-eastern arm of the Atlantic Ocean bordered by nine countries. Acting almost as one large estuary for the many rivers flowing into it, the Baltic Sea varies greatly in levels of salinity across the basin and consequently, the richness of species found within it also varies. Despite nearly a quarter of the seabed being a 'dead zone', the Baltic Sea is home to a mixture of both freshwater and marine species, including species with high commercial value such as cod, sprat, herring and salmon.

The human-led degradation of the sea's coastal environments has been driven by overfishing, eutrophication (in which agricultural runoff increases the nutrient load of the water), and the removal of rocks from the seabed for use as construction materials. On top of this, the Bornholm Basin in the southern Baltic Sea served as a dumping ground for chemical weapons after World War 2, although the biological effects of releasing more than 10,000 tons of highly toxic agents into the Baltic Sea waters remain largely unknown.

A Rocky Road to Recovery

The Flensborg Fjord in the southwestern Baltic Sea is situated east of the Danish/German land border, and was the focus for Dr Tim Wilms of the Technical University of Denmark and his team in a recent study. This region has been subjected to huge levels of rock extraction for construction materials, with over 10,000 acres of geogenic reef being removed from Danish waters alone over the 20th century.

Like the rest of the Baltic Sea, this region is home to important predatory Baltic cod (Gadus morhua). This species utilises rocky reef environments throughout the lifecycle, not only to find prey items but also as a shelter from larger predators such as seals. Similar to other areas, cod stocks have faced the detrimental effects of overfishing, and in the case of the Baltic cod, this eventually lead to a population collapse. Despite the prohibition of rock extraction from Danish waters in 2010, the previous permanent removal of important hard substrate for habitats has rendered the ecosystems in the area unable to recover fully without positive human input.

Dr Wilms and his team wanted to test whether recreating lost habitats would allow for the successful regeneration of these degraded ecosystems, and if this method could be one piece in the puzzle trying to recover Baltic cod populations.

Dr Wilms and his team visited the study area in Flensborg Fjord on a daily basis to collect thousands of video clips. Left to right: Johan M. Sørensen, Dr Tim Wilms, Carl Baden.

Addressing a Longstanding Debate

A longstanding debate in conservation biology is on the importance of Single Large or Several Small (SLOSS) habitats for ecosystem restoration. The majority of SLOSS studies examining marine environments have shown that Several Small habitats have greater benefits than a Single Large habitat, despite the responses of interest differing between studies.

In a marine setting, geogenic or boulder reefs are an ideal habitat to examine the importance of SLOSS for restoration ecology due to their relative isolation from other habitats and the possibility to manipulate their spatial arrangement. Studying boulder reefs also provides important ecological data input that can be taken into consideration in the construction of new hard coastal management schemes such as sea walls and other ecological engineering schemes.

Reef Restoration

Dr Wilms and his team selected a soft-bottomed sandy area as their study site, a region historically featuring geogenic reefs. A before-after control-impact sampling methodology was carried out across six well-spaced sample sites of equal area and water depth.

During pre-restoration sampling, all six sites were surveyed daily by the deployment of 3–4 remote underwater video systems per site that were set to record for 2 minutes per hour. Video footage recorded the presence of any marine species in the frame, and a side scanner was used to scan the sea floor for the desired substrate (i.e., sandy bottom).

Using rocks taken from a Norwegian quarry, reef restoration was carried out on four of the sites, leading to two sites containing a Single Large reef, two sites containing 16 Several Small reefs in a 4x4 configuration (of the same rock diameter and volume as the Single Large reef), and two sites remaining as control sites. Surveying was then carried out again across all six sites 6 months post-restoration.

What Fish Did They Find?

The relative abundance of each species was measured by analyzing each video frame and counting the maximum number of obvious individuals, both mobile pelagic (found within the water column) species such as herring or cod and slow-moving benthic (ground-dwelling) species such as starfish. Numbers of individuals were counted per frame to prevent double counting and identified to the lowest possible taxonomic category. Due to the lack of a downward-facing camera, sessile (immobile) species were excluded from the specific species count, but the total proportion of vegetation or boulder cover was estimated by what was visible within each video frame.

Oh My Cod, That's Amazing!

In terms of species abundance, variations were found between Single Large and Several Small reefs. For example, sand gobies (*Pomatoschistus sp.*) were found in higher abundance at Several Small reefs. These soft-bottom species are often found in lesser numbers on large reef systems but were found to thrive in and around areas between patches of reef.

Importantly, not just environmentally but also with positive commercial implications, cod numbers were found to have increased dramatically around the restored reef sites. Cod sightings increased on average by around 60 times more at Single Large reefs than at control sites, and a whopping 130 times more than the control at Several Small reefs! The data also suggest a probability of nearly 99% of a positive restoration effect on cod abundance – an incredible improvement over such a short period since the reefs were constructed.

And Now We Come to the Fin-ish

A revisit to the survey sites 3 years later found large numbers of juvenile cod sheltering within and feeding around the reef structures. The presence of juvenile fish suggests the successful establishment of a flourishing and productive ecosystem.

The results from this survey are particularly encouraging in indicating that the restoration of geogenic reefs in areas where they have been depleted can have overwhelmingly positive impacts on the abundance of reef fishes found in an area, and the creation of a functioning ecosystem. Despite still not having an answer to the SLOSS debate, it is clear that both types of restoration methods have positive effects over time.

While a positive response to reef restoration efforts was observed from the most prominent reef species in the area, Dr Wilms warns that this alone will not be sufficient to recover and maintain a healthy and thriving ecosystem unless we work alongside other measures to protect the environment from damaging activities such as overfishing and nutrient overload.

Meet the researcher

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UNVEILING THE PAST: USING STATISTICAL COMPUTATION TO CHARACTERISE ANCIENT CLIMATES

Throughout the earth's history, the prevailing climate has changed over and over. To gain insights into the history of our planet, scientists use clues uncovered from the earth's surface. However, not all periods in the earth's history are equally represented in the geological record. **Dr Michael Gipp** is using the surprising similarities between computer algorithms and complex natural systems to describe our ancient climates.

Picturing the Weather

To help create a picture of the earth's climate millions of years ago, researchers study clues known as 'markers' left behind in the geological record. For example, the presence of certain chemical elements can reveal factors such as the oxygen content in the air, or the average rainfall during a past era. However, these markers only give us a very narrow snapshot of the overall climate at the time they were formed, and to create a full picture of the system, researchers are turning to computational models.

Computational modelling methods are incredibly useful when it comes to systems that are too difficult to perform experiments in real life, or to recreate the conditions of a system in the long distant past – such as ancient climate systems. In order to create a computational model, scientists need to determine what the inputs of the system should be, what the outputs should be, and how the two are related. By building up these hypothetical relationships, scientists can change one input, run the simulation, and see what effect that has on the outputs.

The Earth as a Computer

Geophysicist and sedimentologist Dr Michael Gipp has introduced a method to computationally describe the dynamics of chaotic systems. The underlying assumption is that chaotic natural systems can be likened to computation, and as such, can be studied in the same manner. From this perspective, the climate of the earth can be seen as a series of inputs and outputs. An example input is the strength of the sun, and if we were to change the amount of energy the sun puts out then the output, the global temperature, would also change. Clues left behind by ancient climates in the geological records include magnetic sediments and specific chemical isotopes (types of atoms).

The climate of the earth is an incredibly complex system, with a huge number of different potential inputs and outputs. To further complicate this, some of the inputs may be dependent on each other, and are therefore also outputs! Dr Gipp recently likened this to working out the computational details of an unknown programme running on an unknown operating system with an unknown computational architecture.

This may sound like an insurmountable problem, but by using some clever algorithmic tricks researchers can tease out information from very limited starting data. Dr Gipp aims to create a description of the invariant properties

of the climate in central Asia starting from 2.2 million years ago. The climate at the time – the Asian Paleomonsoon – was characterised by high levels of rainfall. In the geological records, a good indicator of the moisture in the climate comes from markers in the soil and sediment layers deposited at the time. From these, Dr Gipp can build up a picture of the climate over millions of years, identifying periods of stability and also when the climate changed rapidly.

Chains of Probability

Dr Gipp starts by building a Markov chain from the sequence of periods of stability in the climate. By building multiple Markov chains relating all the available markers, Dr Gipp forms a 'hierarchy' of all the available clues. From this, he can work out what the climate would have been in eras where the geological record is incomplete from the known markers in the record from either side of the gap.

For example, the geological marker 'A' is always followed by marker 'B', 'B' can be followed by 'A' or 'C', and 'C' can be followed only by 'A'. If the geological record shows marker 'A', a gap, then marker 'C', then we know that the marker in the gap must be 'B'. The probability relations between the markers that Dr Gipp is using are rather more complex, but by building up layers of Markov chains in what are called Epsilon Machines, he can build probability maps of which markers were present at different time periods, even if the geological record is missing.

Dr Gipp found that early in the period, the climate was drier and was much more stable relative to the more recent period from around 1 million years ago which has seen much more variation in rainfall. Dr Gipp then compared his results on the rainfall markers to an earlier work of his investigating total global ice coverage. Both sets of markers showed more variation after around 1 million years ago, and the increased variation in magnetic markers for higher rainfall corresponded with a marker that suggested higher total ice coverage. By comparing these patterns, Dr Gipp can now start using markers that show ice levels in his Markov chains to help describe the rainfall and vice versa.

Critically, Dr Gipp's novel work building a nest of interlinked probability chains also allows him to describe climate events that are not represented in the geological record. As more markers are discovered and added to the algorithm, the characterisations it creates become increasingly accurate, allowing a better understanding of how climate systems have changed over millennia. The next steps are the refinement of the algorithms, helping determine what triggers the transfer from one marker type to the next, and to account for different interpretations of what some markers might mean. Using these computational methods, Dr Gipp is now shining light on the weather of eras long since past.

Meet the researcher

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In 1996, Dr Michael Gipp completed his PhD on glacially influenced marine sedimentation at the University of Toronto in Canada. Since then, he has been made a fellow of the Geological Association of Canada and a member of both the American Geophysical Union and the Association of Professional Geoscientists of Ontario. Over his career spanning geology and earth science, Dr Gipp has also taken part in several field research expeditions, such as establishing marine mining feasibility in Ghana, exploration for diamonds in Finland and the Northwest Territories of Canada, and nine geological survey cruises in the western Atlantic Ocean. Dr Gipp has shared his knowledge through various academic posts, teaching on topics ranging from high school maths to university geophysics. Currently, Dr Gipp's interests are focused on conducting computational studies into paleoclimates and creating new computational tools to understand ancient climates.

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AWARE: CRITICAL CLIMATE DATA INFORMS WEST ANTARCTIC ICE MELT

The West Antarctic Ice Sheet (WAIS) is one of Earth's most rapidly warming regions, holding huge implications for global ocean rise and large-scale weather events. Yet, despite its influence on large-scale climate patterns, the WAIS remains one of Antarctica's most poorly studied areas. **Dr Dan Lubin**, of the Scripps Institution of Oceanography at the University of California, San Diego, brought renewed interest to this neglected but critical region with the AWARE programme, one of Antarctica's most extensive scientific campaigns yet. The programme seeks to improve our understanding of the physical processes influencing the West Antarctic to improve global model simulations.

The ARM West Antarctic Radiation Experiment

Beginning with the 1957 International Geophysical Year, researchers conducted atmospheric observations in West Antarctica including radiosondes, but these critical observations ended by 1967. After that, only a small handful of Automatic Weather Stations (AWS) provided basic surface meteorological data for the West Antarctic, one of the most remote regions on the continent. It wasn't until 48 years later that scientists returned to collect more data in the area. By that time, in 2015, the climate had changed significantly. Collectively, humans emitted an astonishing >30 billion more tonnes of greenhouse gases between 1967 and 2015, fundamentally altering weather patterns and causing large-scale ice melts threatening to cause global sea level rise. Studying weather patterns in this region has always been important, but collecting accurate climate data is now imperative in the face of climate change.

Antarctica contains around 90% of Earth's ice, and West Antarctica's floating ice shelves stabilise the continent's ice sheets. Any changes in air circulation that affect surface warming in the West Antarctic can threaten the integrity of these ice sheets and contribute to massive global sea level rise. To accurately predict how Antarctica's ice sheets will respond to changing weather patterns, we must understand how much heat radiation makes it to the ice to cause surface melt.

Unfortunately, the region's remoteness has made it challenging to establish advanced atmospheric science set-ups like those present in the other areas of Antarctica. In 2015, a team of researchers led by Dr Dan Lubin from the Scripps Institution of Oceanography, partnered with the Atmospheric Radiation Measurement programme (ARM; managed by the United States Department of Energy) and the United States Antarctic Program (USAP; managed by the National Science Foundation). ARM collects atmospheric data in climate-critical areas worldwide. Dr Lubin and his colleagues

A sonic anemometer measuring near-surface turbulent energy fluxes at Siple Dome in West Antarctica. Credit: Dan Lubin.

spearheaded efforts to establish the ARM West Antarctic Radiation Experiment (AWARE) to gather critical climate data on the West Antarctic Ice Sheet (WAIS).

Using ground-based measurements, satellite data and atmospheric modelling, AWARE investigates how atmospheric radiation affects the ice sheet to contribute to our understanding of the broader climate system. The project has already provided significant insights into our understanding of WAIS. Using the most advanced and complete set of equipment for atmospheric and climate

Due to the logistical challenges, AWARE was allowed only one LC-130 aircraft mission to transport equipment and personnel from McMurdo to the WAIS. Credit: Dan Lubin.

science ever sent to Antarctica, climate scientists are already using AWARE's massive dataset to test and refine the climate models we use to predict and prepare for climate change.

An Impressive Dataset

In the first round of AWARE measurements, the team deployed some ARM climate research facility equipment directly on the WAIS ground near an ice-core drilling station. This effort represented the first climatological suite of measurements researchers have taken in this area for over 40 years. This facility was only in place during the Antarctic summer because of the harshness of winter conditions on the equipment.

However, the team also wanted to use the finest, most complex tools available to gather data relevant to cloud formation and aerosols, tiny particles suspended in the atmosphere that come from natural and human-made sources. The closest station where they could deploy this equipment was McMurdo station on Ross Island, adjacent to the Ross Ice Shelf. They set up the equipment, which took measurements from January 2016 to January 2017. Together, the two campaigns – on the WAIS and at McMurdo station – resulted in 14 months of climatological data relevant to the WAIS.

Fourteen months is not long enough to study the long-term effects of climate change on Antarctica. However, with these first measurements on WAIS cloud properties and surface radiation, the researchers hoped the data would help them understand the surface energy balance of Antarctica, which impacts ice melt and sea-level rise.

Initial and Critical Results

A major goal of the AWARE campaign was to compare the Antarctic climate with the better-studied Arctic, which scientists know is strongly influenced by persistent cloud cover. In a 2020 review of the AWARE data by Dr Lubin and colleagues, they found that cloud properties in the Antarctic were significantly different from those in the Arctic. The Antarctic clouds over Ross Island were thinner and less persistent than Arctic clouds. The researchers attribute this difference in cloud properties to the two regions' unique atmospheric and meteorological conditions. For example, the Antarctic has a much drier atmosphere, which leads to fewer clouds and less precipitation. Also, much of the Antarctic atmosphere over the ice shelves is influenced by adjacent mountain ranges; and the vertical air motions cause different partitioning between liquid water and ice in clouds compared with the Arctic Ocean.

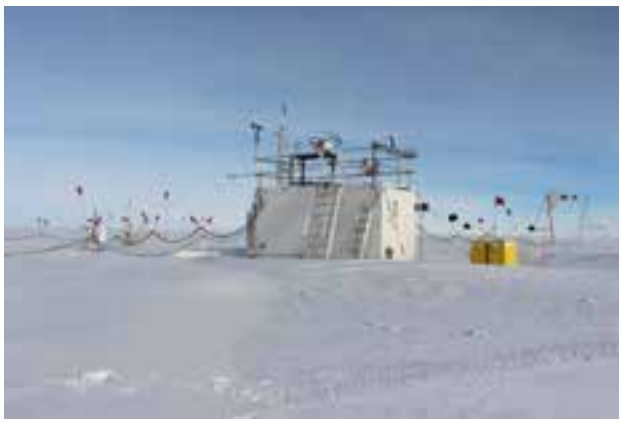
Another key focus of the initial AWARE campaign was to demonstrate the role of aerosols on cloud formation and the Earth's climate. Aerosols are tiny particles suspended in the air from natural and human-based sources. The researchers used a variety of instruments to measure aerosol concentrations, size distribution and properties, such as their ability to absorb or scatter sunlight.

One of the key findings of the AWARE campaign was that the Antarctic has a much lower concentration of aerosols compared with the Arctic. The researchers attribute this finding to the remote and isolated nature of the continent, as well as its low population density and lack of industrial activity. This result implies that assuming similar aerosol composition in the Arctic and Antarctic will lead to incorrect climate model predictions.

Dr Lubin stresses that we shouldn't ignore or neglect aerosol abundances when creating models that predict cloud cover and composition. The researchers emphasize that Antarctic aerosols likely still significantly influence cloud properties, and their composition and unique properties deserve further study.

Climate Modelling Applications

The modelling applications now possible due to the AWARE campaign are perhaps the most promising and exciting aspect of the programme. Researchers used a serendipitous event in 2016 when a strong El Niño year coincided with a significant West Antarctic melt event. During El Niño, sea surface temperatures in the Pacific Ocean are warmer than average. Researchers know that ice melts in Antarctica have correlated with the weather phenomenon but lacked the data to investigate the trend further.



AWARE meteorological and atmospheric remote sensing equipment in operation on the WAIS. Credit: Dan Lubin.

Siple Dome Field Camp, a small summer-only facility in West Antarctica staffed by only four people, where Dr Lubin's 2019 follow-on campaign was deployed. Credit: Dan Lubin.

Fortunately, the AWARE campaign's sea container equipment at the edge of the melt recorded the meteorological patterns during the melt.

This event and AWARE's serendipitous data collection allowed scientists to study and test the accuracy of their regional and global climate models. The researchers used the AWARE data to evaluate the popular Polar Weather Research and Forecasting regional model, a version of the Weather Research and Forecasting model.

The researchers compared the model simulations against the actual observations from AWARE. In general, Dr Lubin and his colleagues found that the models failed to capture the relatively high occurrence of liquid water in the clouds, which caused the predicted temperatures to be cooler by several degrees than what was observed. This miscalculation has significant consequences for the model's estimation of how much energy is in the WAIS snowpack.

The AWARE data analysis also revealed a potential reason why El Niño might cause ice melts. In a 2017 paper examining the event, Dr Lubin and his colleagues propose that El Niño brings warm air to the area, explaining why surface melt tends to be associated with El Niño events. Since experts predict that the frequency of El Niño events will rise over the twenty-first century, the researchers note that more events could promote more frequent melt events. However, the researchers caution that the relationship between El Niño and climate is complex, and we are only beginning to understand how the event influences Antarctic weather patterns.

Overall, this case study demonstrated the ability to use AWARE data to help identify and correct model biases and help scientists study whether we can reliably expect similar ice melts after El Niño events.

Onwards and Upwards

Dr Lubin and his colleagues continue to deploy new portable equipment spun from AWARE's ARM technology to other areas in West Antarctica. For example, in 2019, Dr Lubin took transportable solar-powered equipment to Siple Dome, an ice plateau in West Antarctica near ice streams of great scientific interest, to take data on surface energy measurements and conduct cloud remote sensing. The goal was to continue data collection on the clouds that persist over Antarctic ice sheets, which regulate how much heat gets to the ice and can induce ice melt that weakens the ice shelf structure.

The expedition showed that AWARE's follow-on mission to Siple Dome was successful, highlighting the ability of the field equipment to be deployed in even more remote and rugged conditions. Dr Lubin and his team are using these data to validate cloud simulations over the area, and these efforts are ongoing.

Confronting Climate Change

The West Antarctic Ice Sheet is a critical region in the Earth's climate system, and the AWARE programme is improving our understanding of physical processes in the region. The success of the project is undoubtedly due to the collaborative effort of researchers from different fields and countries. Using the massive dataset generated through AWARE, scientists are already improving their climate models to predict and prepare for climate change.

The programme has broader impacts beyond improving our understanding of the West Antarctic. It is training the next generation of climate scientists and engaging the public in understanding climate change. As we continue to face the threat of climate change, programmes like AWARE are essential to our efforts to mitigate its impact on our planet.

Meet the researcher

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Dr Dan Lubin is a research physicist at the Scripps Institution of Oceanography at the University of California, San Diego. He received his MS in astronomy and PhD in geophysical sciences from the University of Chicago. With over 30 years of experience in climate science and astrophysics, Dr Lubin has specialised his expertise in studying climate change and the impact of solar radiation on the Earth's climate system, using advanced remote sensing instruments. Dr Lubin is the principal investigator of the ARM West Antarctic Radiation Experiment, which is investigating the climate on the ice shelves in West Antarctica. Dr Lubin has published extensively over his career, has been awarded substantial funding, and has been the recipient of numerous awards in recognition of his pioneering work.

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FUEL CHANGE: RIDDLES, PARADOXES AND ENIGMAS IN ENERGY TRANSITIONS

Throughout history, we have relied on many different energy sources. Initially, wood was used for heating and cooking; as industry grew, we moved to fossil fuels; and the scientific advances of the 20th century allowed us to harness sources such as nuclear, solar and tidal energy. The transition from one fuel type to another has led to the identification of some intriguing paradoxes. **Professor Nuno Luis Madureira** from the University Institute of Lisbon studies these transitions and is shedding light on this fascinating subject.

Paradoxical Progression

The forward march of technology is not without its unexpected deviations and unforeseen problems, and the story of energy transitions is no different. The journey from using branches to fuel fires keeping early hunter-gatherers warm on cold nights, to nuclear power stations providing electricity to millions of homes is one example of the many technological advancements and transitions undertaken in the course of humanity.

The main factor allowing the efficient harnessing of a new energy source is advancing technology, with new 'green' options such as solar, wind and tidal sources being the focal point of much current research. However, the transition from one energy source to another may not be as smooth as one might expect. Professor Nuno Luis Madureira from the University Institute of Lisbon in Portugal studies the paradoxes and counterintuitive events that can occur surrounding energy technology. His research provides a set of intriguing lessons from the past, and illustrates some of the pitfalls that can occur if we're not careful in the future.

Efficiency and Consumption

Professor Madureira's first example is the Jevons paradox. The English economist William Stanley Jevons noted in 1865 that as the production of energy from coal got more efficient, people made use of less coal but the total demand continued to rise. Jevons highlighted two potential mechanisms underpinning this paradox. Firstly, as the efficiency of energy extraction increases, the cost of each unit of energy decreases. This cheaper energy is now affordable by more individuals and industries, and the total demand for fuel will increase. The second potential mechanism is that as energy is cheaper, less of people's money has to be spent on it, leaving them with more disposable income that will then be spent on goods and services, increasing the demand on industries which will require more energy to keep up.

The current definition of the Jevons paradox is that 'with fixed real energy prices, energy-efficiency gains will increase energy consumption above what it would be without these gains'. Professor Madureira explains that the Jevons paradox is a useful warning when adopting new energy

technologies, especially when the resources are non-renewable, as the increased demand can lead to unexpected problems such as shortages and resource exhaustion. The impact of societal effects should therefore be considered before the adoption of a new, seemingly better, technology.

Destruction and Conservation

Nuclear energy is one of the most controversial energy sources, bringing with it a clear potential for disaster if not properly utilised. However, the development of this energy source from its beginnings as a weapon neatly highlights Professor Madureira's 'destruction paradox'. Professor Madureira reports that nuclear testing has had lasting benefits for our understanding of the natural world and how 'technologies prone to destroy the planet also fostered its conservation'.

This paradoxical path began with the unexpected reach of radioactive fallout from the Pacific island nuclear tests shocking the public, who demanded better information on nuclear weapons. As a result, the US Atomic Energy Commission was ordered to carefully analyse the effects of nuclear weapons on the environment.

In the 1950s, the Odum brothers were working with the AEC on a study of Eniwetok atoll in Micronesia, studying the path and concentrations of radioactive isotopes through the environment. It was here that they first put forwards a new theory about how energy and nutrients move through ecosystems, explaining how flora and fauna transfer energy through a food web, and laying the foundation for the modern understanding of ecosystems. Finally, the technological advances accompanying nuclear research gave scientists new tools to track radiological isotopes through food webs and track these energy transfers. Technologies prone to destroy the planet also fostered its conservation. Professor Madureira highlights that greater environmental awareness, understanding, and technology would not have developed without the initial destruction caused by nuclear weapons.

It's Not Easy Being Green

Renewable sources of energy seem to be the answer to the Jevons paradox – the increased demand for fuel is easy to provide when the resource appears limitless. Additionally, harvesting renewables such as wind and solar energy does not produce hazardous waste, unlike nuclear or fossil fuels. However, Professor Madureira warns that there is a paradox that should be carefully considered before leaping headfirst into a full-scale transition to green energy.

Professor Madureira's paradox is that limitless potential energy can, in effect, run out. As many green energy technologies require rare materials, such as indium and gallium in photovoltaic cells, there are limits on the number of generators we can build. Additionally, as these materials become rarer, the economic and environmental cost of extracting them rises: more energy is needed to produce energy. Finally, Professor Madureira draws attention to the fact that renewable energies are often only cost-effective in certain locations, and that these will eventually all be utilised. The energy from wind, solar, and tidal may be functionally limitless, but the materials to build and the locations to place cost-effective generators certainly are not.

However, Professor Madureira is keen to point out that these paradoxes should not prevent the move to renewables; rather it is vitally important to think carefully about the continued growth in demand for energy and how that can be managed. He explains that the energy paradoxes of efficiency increasing consumption; destruction enabling conservation; and the limitations on limitless energy, can all be learned from by examining both the societal and technological driving forces. By learning from the past, and planning before we leap, we can avoid many of these potential traps in the years to come.

Meet the researcher

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Professor Nuno Luis Madureira is a current full professor at the University Institute of Lisbon (Instituto Universitario de Lisboa) in Portugal. His far-ranging work covers the fields of economic, contemporary energy and environmental history. Professor Madureira has a large body of academic papers to his name, having published in a wide range of academic journals including the Business History Review, Frontiers in Energy Research, and Energy Policy. Additionally, he has contributed chapters to encyclopaedias and written his own books, including 'Key Concepts in Energy', published in 2014. Professor Madureira has been an active contributor to several research bodies and committees over the course of his career, including the Foundation for Dutch Scientific Research Institutes and the European Science Foundation as well as being a visiting scholar at Harvard University and the University of California Berkeley.

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EXPLORING HOW CROPS CAN OVERCOME SALT STRESS

Plant health is inextricably linked to the soil. An excess of salt can affect a plant's ability to uptake other nutrients and reduce its overall growth. For crops, reduced growth translates to lower yields. Most research on this issue focuses on growing cultivars that are salt tolerant. **Dr Vanaja Kankarla** inspected the problem from a different angle. Her team studied how two forage crops, alfalfa and triticale, responded to saline water. The team's results highlight triticale's outstanding salt tolerance and shows that saline irrigation may actually boost alfalfa yields.

Saline Soils

Saline soils present a significant obstacle to global agricultural and food security goals. Excess salts in soil can prevent plants from taking up water and other nutrients. As a result, plant growth can be stunted or even stopped. Roots, which are the first part of a plant to come in contact with salts in the soil, show the first signs of damage.

Globally, about 80 million square kilometres of arable land features very salty soils. Salt toxicity can occur naturally, but anthropogenic activities have vastly exacerbated the issue, particularly in arable lands. For example, poorly draining soils and excessive fertiliser use can lead to salt accumulation. At its worst, saline croplands eventually become degraded, dramatically decreasing agricultural productivity. Forecasted temperature increases with climate change, along with increasing prevalence of droughts, will accelerate the issue.

To combat this issue, some researchers are studying how to increase the salt tolerance of crop roots. Scientists and plant breeders have also developed many varieties of crops that are salt tolerant. Other advancements include developing more sustainable farming techniques to reduce over-draining soils, which can lead to salt accumulation. However, the complexity of this problem requires a multi-pronged approach and interdisciplinary cooperation.

Dr Manoj Shukla, Dr Vanaja Kankarla and their colleagues have significantly contributed to this growing body of research. In her previous work, Dr Kankarla showed that alfalfa and triticale (a hybrid of wheat and rye) are tolerant to irrigation from brackish groundwater – which contains a mixture of fresh and seawater. They also showed that these two crops tolerate irrigation with 'reverse osmosis concentrate' – the wastewater left over from de-salination processes. Both brackish groundwater and reverse osmosis concentrate have elevated levels of salt.

Farmers grow alfalfa as feed for livestock and other animals. Alfalfa crops are very important to the US economy and can tolerate extreme climate conditions. Like alfalfa, triticale can provide high

yields in low-quality soils, and has a high tolerance to stress, drought, saline soils, and extreme temperatures. Both crops will be critical in efforts to meet global food and forage demands, especially in saltier environments.

In a 2020 study, Dr Kankarla and her colleagues investigated whether irrigating alfalfa and triticale with saltwater changed the root architecture of these species in ways that would promote increased tolerance to salt stress.

To evaluate the response of these species to salt stress, they irrigated both plants with brackish groundwater and reverse osmosis concentrate. The goal of the study was to determine whether salt stress stimulates responses in the roots that directs more resources to the shoots and leaves of the crops. Because farmers harvest the leaves and shoots, the researchers hypothesised that they could use saline treatments to promote higher crop yield.

Triticale Emerges as Salt Superstar

Under controlled greenhouse conditions, Dr Kankarla and her team conducted two replicated experiments. The experiment was split into equal numbers of alfalfa and triticale with different watering treatments. They watered one group with tap water as a control. Then, they watered one group with brackish groundwater and another with reverse osmosis concentrate.

To document the plants' responses to the irrigation treatments, Dr Kankarla measured root mass and density. They also imaged the roots, allowing them to accurately measure total root length, average diameter, surface area, root volume, and the number of root tips, forks, and crosses. These fine measurements would tell the researchers whether the root architecture changed in response to salt stress. Finally, they measured the ion concentrations in the root samples. All of these factors helped the researchers to understand how the roots and shoots responded to saline conditions.

The results showed that both plants responded to increased levels of salt, but in different ways. The root mass of alfalfa plants watered with the brackish water and osmosis concentrate was significantly higher than alfalfa plants in the tap water group.

In contrast, triticale experienced the opposite trend. The root mass of triticale under saltwater treatments was much lower compared with triticale plants in the tap water group.

Notably, triticale irrigated with saline water had much higher stem and leaf mass, which farmers harvest for animal feed. Essentially, although saltwater had negatively affected the size of roots, it actually increased the mass of the triticale leaves and stems.

Mechanisms

When the researchers imaged the roots, they compared the root architecture – root age, type and branching – of the plants irrigated with tap water and those irrigated with saline water. In alfalfa, the researchers noted clear differences in root branching and shape between the tap water and saltwater groups. For example, alfalfa's root length, volume and density all increased under saline conditions. These traits would give alfalfa an increased ability to grow, extend, and absorb nutrients inside the soil, and explains how alfalfa's root mass increased under saline conditions.

In contrast, the root architecture of triticale seemed largely unaffected by salinity. This lack of response is astounding, and suggests that triticale barely noticed the salt – demonstrating its superstar status when it comes to salt tolerance.

To explain their findings, the researchers hypothesised that high levels of calcium in the groundwater and reverse osmosis concentrate helped alfalfa increase its root mass. Calcium is responsible for maintaining both soil structure and normal plant metabolism under saline conditions. However, the researchers pair this interpretation with a disclaimer, noting that we need more research to address the role that calcium might play in the plant's response to salt. The team's results also suggest that alfalfa restricted salt to its roots to reduce the potential for excessive sodium accumulation in the shoots.

Salt-tolerant Forage Crops

Overall, Dr Kankarla's study sheds light on two very important crops that are known to respond well to salt stress.

Their research demonstrates that triticale can be easily irrigated with brackish groundwater and reverse osmosis concentrate, which will allow farmers to conserve their available freshwater for other uses. In alfalfa, root system changes actually enable the roots to accumulate more water and nutrients when irrigated with saline water. Based on these findings, Dr Kankarla's team recommends that farmers use brackish groundwater and reverse osmosis concentrate to irrigate alfalfa and promote a positive stress response, allowing farmers to easily boost their crop yields and conserve freshwater.

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Dr Vanaja Kankarla grew up in Hyderabad, India. Coming from a highly disciplined and cosmopolitan family, she travelled throughout most parts of India. She discovered her interest in agricultural science while working with rural Indian communities. Dr Kankarla graduated with a Bachelor's degree in Agriculture from Acharya N. G. Ranga Agricultural University, India. In 2013, she moved to the US to pursue a Master's degree in Plant and Soil Sciences from Tennessee State University, Nashville TN. Later in 2019, she graduated with her doctorate in Plant and Environmental Science from New Mexico State University. Dr Kankarla completed her two years of postdoctoral research at Texas A&M University, and in 2022, she began an Assistant Professor appointment in the Marine and Earth Science Department at Florida Gulf Coast University. Her research combines agronomy, soil science, crop-weed nutrient management and competition studies, and developing decision support tools for solving agricultural and environmental challenges. She loves to work with students who are enthusiastic about research. She enjoys teaching, mentoring and watching curious young minds learn and grow. Over the last few years, her work has been recognised with many awards, including the 2022 Postdoctoral Research Award in recognition of outstanding research from the Department of Soil and Crop Sciences, Texas A&M University, the 2019 Dean's Award of Excellence in recognition for outstanding graduate student achievement from the Department of Plant and Environmental Sciences, NMSU, and the 2018 'Young Innovators Creating a Better World for All' award by the Women Economic Forum (WEF). Dr Kankarla has positioned herself as one of agricultural science's most promising young women scientists.

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FUNDING

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Florida Gulf Coast University

PROTECTING BERRY CROPS FROM INVASIVE PESTS WITH EXCLUSION NETTING

Berry crops are vulnerable to numerous invasive pests, including spotted wing drosophila. These fruit flies have caused significant losses for farmers growing berries in different parts of the US, Asia, and Europe. A few years ago, **Dale-Ila Riggs**, the owner and operator of The Berry Patch, developed and implemented a series of exclusion netting systems that can effectively protect berry crops from spotted wing drosophila and other environmental threats, reducing the need for chemical pesticides.

A Major Risk for Berry Crops

Successfully growing berries, such as strawberries, raspberries, blackberries, and blueberries, can be a very challenging task. Berry crops are vulnerable to numerous pests and environmental threats, including severe weather, fungi, rodents, moths and fruit flies.

One of the most destructive fruit fly species for berry crops is the spotted wing drosophila. These invasive fruit flies, which originate from southeast Asia, have now become a major threat to soft-skinned fruit crops across the US and Europe.

Spotted wing drosophila can cause significant damage to berries. Unlike other species of fruit fly, they lay eggs into soft-skinned fruits as they are ripening. Fruits infested by their eggs typically decompose from the inside, due to the larvae feeding on them.

Raspberries, blackberries, strawberries, cherries and blueberries are particularly vulnerable to spotted wing drosophila. However, this invasive pest can also infest other soft-skinned fruits, including grapes, along with damaged pears, peaches, nectarines, and tomatoes. Noticing these flies and protecting fruits from potential infestations is now a critical challenge for many crop growers.

To reduce the risk of infestations, most non-organic farmers use chemical pesticides, with varied and inconsistent results. Such pesticides can cause great harm to natural enemies, butterflies and other pollinators, damaging local ecosystems and ecosystem services. Many consumers are also concerned about the potentially harmful effects of pesticide residues on the berries they eat.

Organic farmers, on the other hand, rely mostly on a single 'organically approved' pesticide, which can only be applied twice to a crop, before rotating to other organic materials that have limited effectiveness.

Exclusion Netting

A few years ago, Dale-Ila Riggs, Plant Science graduate and owner of The Berry Patch in Stephentown, New York State, devised an exclusion netting system that protects berry crops from spotted wing drosophila and other pests, reducing the need for chemical pesticides. The main idea behind this system is to physically exclude pests from the sites where crops are growing. 'The biggest problem with spotted wing drosophila is that by the time you know it is on your farm, it is virtually too late to control it,' explains Riggs. 'It lays its eggs in fruit that are just starting to ripen and matures so quickly that when ripe fruit is picked it is contaminated by maggots. Reliable traps have not yet been developed, so growers have had to

Dale-Ila Riggs and her husband, Don Miles, standing under their exclusion netting on their farm.

The team's newer support structure and netting system that was erected in 2020.

All exclusion netting stored away for winter.

abandon integrated pest management principles of monitoring and treating at a given threshold.'

In the Northeast, where The Berry Patch is located, many farmers have historically been able to grow blueberries without using insecticides. As such, many blueberry growers do not own spraying equipment and have no interest in using pesticides. However, spotted wing drosophila first appeared in the region in 2011, and has since caused significant damage to local crops, resulting in substantial financial losses for farmers.

Riggs started working on her exclusion netting system after she experienced a 40% loss in her blueberries and 25% loss in her raspberries in 2012 due to a spotted wing drosophila infestation. She soon realised that the existing solutions for protecting berry crops from these invasive pests are far from ideal. This motivated her to develop an alternative approach.

In 2014, Riggs adapted a bird netting support system for her blueberry crops to test the concept of exclusion netting. Remarkably, she found that this system protected her crops from spotted wing drosophila infestations far more effectively than the pesticides and products she had tried before.

A Sophisticated Netting System

Adult females of the spotted wing drosophila species are approximately two millimetres in length and around one millimetre wide. To prevent them from accessing crops and laying eggs inside them, the netting system created by Riggs has openings of 1.05 x 0.60 millimetres.

The first version of Riggs' exclusion netting system was created by combining two 26-foot-wide pieces of 'ExcludeNet' netting, placing it over her bird netting support structure made from high tunnel hoops that she had in her blueberry field. Combined, these two pieces of netting made up a 51-foot-wide sheet that could be applied down the 250-foot length of her established blueberry rows.

In contrast with pesticides and other solutions to prevent berry crop infestations, the netting system created by Riggs only needs to be installed once a year, thus eliminating the need to continuously purchase new products. Crop growers have reported that these initial installation costs were returned to them through their better crop yields after just one or two years.

To be effective, a netting system should be deployed after the crops have already been pollinated, but before fruits start gaining colour. Depending on the size of greenhouses or plantations and on the number of workers employed, setting up the netting system and storing it for the winter can take from a few hours to a couple of days.

From left to right: Laura McDermott, Natasha Field, Don Miles, Dale-Ila Riggs and Chris Callahan.

Large-Scale Implementation

After introducing and testing her exclusion netting system back in 2014, Riggs achieved highly promising results. Today, she is further developing and evaluating her system, while also training berry growers in the Northeast to successfully construct and implement netting systems on their own farms.

Her new design, testing and education efforts are supported by a $15,000 grant awarded to her by Sustainable Agriculture Research and Education (SARE), an organisation that offers funding for projects that increase the sustainability of agricultural practices in the US. SARE had also financially supported her initial development and implementation of the exclusion netting system.

Riggs' new research and development effort has many complementary objectives. Firstly, she hopes to increase the production rates of berry crops in the Northeast, using the exclusion netting system she developed to prevent fruit fly infestations and other forms of crop damage. She has achieved phenomenal yields and approximately double the fruit size of other local blueberry farms. This is due in part to the elimination of weather-related losses from heavy rain, wind, and hail. She also believes that the protective nature of the netting has a physiological impact on flower bud formation and fruit development.

Concurrently, she hopes that her work will improve the management of farm businesses, helping owners to plan for and manage pest infestations more effectively. As her netting system eliminates the need for insecticides, it could also help to improve the quality of production systems, for instance by facilitating the transition towards fully organic crop growing.

Training Berry Growers

As she continues to develop and evaluate her exclusion netting system, Riggs is also collaborating with researchers at different universities across the US, in order to develop tools for educating crop growers about the system. Her hope is that this will ultimately increase crop growers' confidence in the system and encourage them to implement it on their own farms.

'As growers come to the realisation that spotted wing drosophila is here to stay, more of them are interested in using exclusion netting,' Riggs explains. 'A major stumbling block for acceptance of this technique is the lack of commercial companies providing support structures and the lack of a tested design and plans for growers to construct their own structures.'

To overcome the limitations preventing many growers from implementing and testing the exclusion netting system, Riggs and her colleagues are now building and testing an engineered system that could be easier for farmers to replicate using widely available netting and other components. In addition, they are creating good-quality construction plans, a list of materials, and other resources that could guide growers who are introducing the system.

'I want to teach growers, mainly through hands-on construction workshops and YouTube videos, how to build a system for their own farm,' says Riggs.

Sustainable Protection Against Fruit Flies

The exclusion netting system created by Riggs is a valuable, pesticide-free solution to the problem of spotted wing drosophila infestations, which are now routinely occurring across the US and Europe. Nine years of evaluations have highlighted the great benefits of the system, showing that it outperforms insecticides in protecting berry crops from both spotted wing drosophila and other harmful pests.

'We have had fantastic results with our exclusion netting system,' says Riggs. 'I have now been using it for nine years, learning and improving it slightly each year, and we have had less than 0.50% infestation of spotted wing drosophila over those nine years. In four of the nine years, we have had zero percent infestation over a 10-week harvest season, along with other beneficial effects.'

The YouTube videos, farm-based workshops, and additional resources that Riggs and her colleagues are currently developing could soon be used by berry farmers and other growers of soft-skinned fruit to improve their practices and better protect their crops from invasive pests. Ultimately, this could also lead to a reduction in the use of chemical pesticides, paving the way for greener and more sustainable agriculture.

Meet the researchers

Dale-Ila M. Riggs
Owner and Operator
The Berry Patch Farm
Stephentown, NY
USA

Dale-Ila M. Riggs is the owner and operator of the Berry Patch of Stone Wall Hill Farm in Stephentown, New York. She holds a BS in Plant Science and International Agriculture from Utah State University and an MS in Horticulture and Adult Education from Oregon State University. After completing her studies, Riggs worked as an Area Horticulture Specialist at the University of Missouri Cooperative Extension for one year, and as an Area Vegetable Specialist at the Cornell Cooperative Extension for ten years. At Cornell, she developed numerous innovative research and education programs. Her work in pumpkin production also earned her the National Crop Production Award from the National Association of County Agriculture Agents. Riggs created the Berry Patch farm in 1998 with her husband, Don Miles, from a worn-out corn field. The farm includes several greenhouses, berry and vegetable tunnels, and a farm store selling fresh and seasonal produce. At the Berry Patch, Riggs is responsible for management, production, and marketing decisions. Her hard work allowed the farm to grow from a part-time operation, with less than one acre of berries spread over 91 acres, to a full-time and diversified operation, which now spans across 210 acres.

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Chris Callahan
Extension Associate Professor of Agricultural Engineering
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Chris Callahan is the Associate Extension Professor of Agricultural Engineering at the University of Vermont and the Director of the Northeast Center to Advance Food Safety (NECAFS). His work focuses on the application of the engineering practice to food systems. Specific engagement is with food producers, processors, and distributors to improve efficiency, quality, safety, and cost control through the integration of technology, systems integration, and process controls. Areas of work include protected culture, postharvest handling and storage, produce safety, and sustainable energy.

Greg Loeb
Professor of Entomology
Cornell University

Greg Loeb earned his PhD in Entomology at the University of California at Davis in 1989. He came to the Department of Entomology at Cornell in 1995, where he established a research and extension program at the New York State Agricultural Experiment Station in Geneva, NY, with responsibilities for arthropod pests of grapes and small fruit crops. Since then, his lab has worked on the biology, ecology and management of a number of arthropod pests of grapes and small fruit crops, with the goal of developing sustainable and cost-effective pest-management tools.

Laura McDermott
Regional Berry Specialist
Cornell Cooperative Extension

Laura McDermot is a Senior Extension Associate and co-team leader at Cornell Cooperative Extension. She is also the Berry Specialist of the Eastern NY Commercial Horticulture Program. McDermot assists berry and vegetable farmers in eastern New York State with many production related topics of concern to direct market farms. She has helped northeastern growers adapt to a changing climate using protected agriculture technology and has conducted a wide variety of applied research relevant to improving the profitability and efficiency of berry and vegetable crop production.

KEY COLLABORATORS

Stephen Hesler, Research Support Specialist at Cornell University
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Sustainable Agriculture Research and Education (SARE)

PROTECTING ALGAE FROM PESTS TO GENERATE SUSTAINABLE BIOFUELS

Algal biofuels offer a renewable and carbon-neutral alternative to fossil fuels. These photosynthetic microorganisms can be grown inexpensively in large ponds, but being exposed to the elements risks biological contamination from other microorganisms. **Dr Robert Pomeroy** and colleagues at the University of California, San Diego, used chemical ionisation mass spectrometry to continuously measure the quantities and compositions of volatile gases produced by algal pond samples, allowing for the detection of infectious species and assessment of the impact such pests have on algal communities.

As the world transitions towards renewable energy sources, biomass is an important source of biofuel for the energy industry and chemical production (including dyes, cosmetics, pharmaceuticals and food additives). Biofuels can be made from algae, plants or biowaste generated by agricultural, industrial and domestic settings, providing oils that are alternative energy sources to the fossil fuels causing climate change.

Cultivating algae in shallow, artificial (raceway) ponds is an economical method of generating the biomass needed for biofuels through the process of photosynthesis (where organisms containing the green pigment chlorophyll produce energy from sunlight, water and carbon dioxide). However, ponds often contain biological contamination from grazing species which reduce biomass quantities through competition between algal species and risks posed by infectious organisms.

Dr Robert Pomeroy and his colleagues at the University of California, San Diego, identified an important need for regular, real-time pond observations to detect infections introduced by grazing microorganisms as soon as possible so that action can be taken quickly to protect pond algae populations.

Detecting Infections to Save Crops

Microalgae can be grown rapidly in small spaces, with few additional resources, to produce large quantities of biomass, making them a sustainable energy source. Algae are often grown in open raceway ponds, with a paddle wheel to maintain water flow, as operational costs are significantly lower than for the laboratory cultivation of biomass. However, the lack of environmental controls on open ponds means that contamination by grazing species [such as viruses, bacteria, fungi and other microorganisms (ciliates and rotifers)] poses a significant challenge to growers. In fact, infections introduced by grazing species can decrease biomass yields by 10 to 30%, reducing the profitability of sustainable biofuel production by hundreds of millions of dollars.

Quickly identifying contamination and infections within algal cultures is therefore key to saving the crop. By providing growers with tools to detect pests as early as possible, appropriate

Credit: Erik Jepson

treatment decisions can be made, such as killing the algal culture, slowing the growth of contaminant species or harvesting the crop before the infection spreads further.

Previous detection methods have used microscopy or automated optical techniques (including flow cytometry, the analysis of particles flowing past lasers) to detect the number of contaminants in a liquid sample taken from a raceway pond. These processes

are cost-effective but time-consuming. Similarly, molecular biology techniques such as qPCR (a DNA measurement tool) can effectively identify grazers but require specialist molecules (primers) to conduct the reaction and sequence DNA in the sample. Therefore, the techniques currently available are not ideal for growers to rapidly sample infected ponds and action treatment procedures, which can be imperative as some grazer infections can destroy 1% or more of a pond's biomass in an hour depending upon the density of grazers.

Real-time Infection Monitoring

Researchers from the Centre for Aerosol Impacts on Climate and the Environment (CAICE), the California Centre for Algae Biotechnology (Cal-CAB), and the Centre for Marine Biotechnology and Biomedicine (CMBB) proposed chemical ionisation mass spectrometry (CIMS) as a real-time monitoring technique, which could identify infections introduced by grazers and the impacts these have on the growth of algal communities.

Algal cultures produce small molecules and volatile gases as by-products of their metabolic reactions during healthy population growth and in response to environmental stressors. Dr Pomeroy and his colleagues suggested that measuring changes in the volatile gases produced by algae could provide an indication of algal population health in a pond, as the volumes and compositions of the gases produced are controlled by factors such as environmental conditions, nutrient availability, light levels, growth rate and the presence of contaminants.

To test the CIMS method, the team measured the gases produced by the cyanobacteria *Synechococcus* elongatus during healthy growth periods. In CIMS, an ionised gas is continuously mixed with volatile gases emitted from a sample inside a container. As the gases mix, interactions between the ions in the injected gas and molecules in the sample gas cause ionisation of the volatile gases. These ionised gas molecules can then pass through a detector and are separated out by mass spectrometry, an analytical tool which measures the mass and charge of molecules.

By analysing the results of mass spectrometry, Dr Pomeroy's team were able to detect the different chemical compositions of gases within samples taken from an algal pond. Steps were also taken to simplify the method, such as continuous measurement of ambient gases, which could easily be observed and eliminated from the sample results. Additionally, the injection of the ionised gas was conducted gently, preventing fragmentation of ions, which would create more ions to be detected by the mass spectrometer and therefore complicate the results. As CIMS can monitor up to 10 samples an hour, the researchers hope that this method can be further modified for use in the field to improve the applicability of this technique in real-world situations and enhance the cost-effectiveness of the process.

Credit: Carolyn Fisher

Alexia Moore and Jon Sauer. Credit :Ryan Simkovsky.

Finding Pests Quickly

Using CIMS, the molecule sulcatone (6-methyl5-hepten-2-one) was identified as a metabolic indicator for the freshwater cyanobacteria *Synechococcus* elongatus. This molecule is a by-product generated during the exponential growth of the cyanobacterial community and the gas's abundance suggests the population is growing healthily.

Synechococcus populations were grown in 20-litre containers and monitored over 28 days. *Tetrahymena* (a single-celled organism) was added to the container, introducing an infection as *Tetrahymena* rapidly grazes on *Synechococcus*. Liquid samples were collected from the containers for daily analysis using microscopy, absorbance spectroscopy and fluorescence spectroscopy to cross-reference with CIMS data. Sterile air was also bubbled through the liquid sample to push gases to the surface and it is these gases that were fed into CIMS for analysis. The mass spectrometer produced 60,000 readings in 1 second, making sample analysis very rapid, and specific peaks on the graph (mass spectrum) revealed the compositions of the volatile gases being produced. In total, 49 ions were found to change in intensity over the lifetime of the experiment, indicating that biological processes were occurring within the algal culture in response to the injection of *Tetrahymena*.

After only 18 hours, nitrogen-based gases, such as ammonia and pyrroline, became more abundant during measurements, suggesting that these gases can help to indicate the presence of grazing species (such as *Tetrahymena*). CIMS was able to identify these changes in gas compositions much more quickly than traditional methods (such as microscopy and continuous fluorescence) which took between 25 and 76 hours longer than the CIMS method to detect infections introduced by *Tetrahymena*. The more timely detection of infection using CIMS is imperative for growers, as the method provides an early warning of contamination and gives growers time to respond to prevent biomass losses.

However, Dr Pomeroy and colleagues noticed that some of the higher density algal samples tested during the study showed a heightened response to microorganism infection than more sparsely populated samples. The denser samples produced larger changes in volatile gas volumes in response to the stressful stimuli (infection), suggesting that the CIMS method would be most successful to monitor dense, mature algal ponds, and that raceway ponds with less biomass may require additional analysis to provide a full picture of the algal community's health.

Refining Use in the Field

This new method shows promise to be an effective tool for continuous monitoring of volatile metabolites to identify grazing in algal ponds. Future research will refine the technique to work on more specific algal-grazer relationships, which will account for variations in the volatile gases produced by different algal species and unwanted microorganisms. Additionally, modifying the method to work in situ at raceway ponds will require addressing environmental contaminants separate from the infecting microorganisms. Dr Pomeroy and colleagues propose a solution to this, by using a sampling interface across a large surface area of pond water, where the CIMS equipment is positioned next to a stream of clean air to minimise local airborne sources of contamination.

Volatile gases provide a proxy for the state of health of the algal bloom, therefore, harnessing the power of CIMS can provide a 1-to-3-day notice of upcoming biomass loss following infection. Identifying infections early can allow for treatment to protect the biomass in ponds and therefore reduce biomass losses for the energy industry. Furthermore, this pest monitoring technique could have wider applicability in other industries that require strict levels of hygiene, such as in the production of beer, cheese, antibodies and laboratory-grown meats. Predators, pathogens and competitors within raceway ponds reduce biomass quality and yield. Clearly, CIMS has the potential to prevent crop destruction by infectious species and increase the profitability of biomass production.

Meet the Researcher

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Dr Robert 'Skip' Pomeroy is an Analytical Chemist and Teaching Professor at the University of California, San Diego. Before teaching here, Dr Pomeroy also obtained his Bachelor of Arts degree in Chemistry at the same university, followed by a Master of Science degree in Analytical Chemistry from Cal Poly Pomona. His education continued with a PhD in Analytical Chemistry from the University of Arizona and a postdoctoral position in the Marine Physical Lab at Scripps Institution of Oceanography. Dr Pomeroy now works across several research centres (Centre for Aerosol Impacts on Climate and the Environment, California Centre for Algae Biotechnology, FF21 and the Centre for Renewable Materials), serving as an educational lead and chemical analyst, and has spent 10 years leading research and development for Southern Grouts and Mortars.

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UNIVERSITY OF CALIFORNIA

PHYSICAL SCIENCE, ENGINEERING & TECHNOLOGY

POKING HOLES IN THE STANDARD MODEL OF PARTICLE PHYSICS

Our understanding of physics changed dramatically in the 20th century, with the advent of the Standard Model of Particle Physics, which builds on quantum mechanics and Einstein's theory of relativity – two of the most successful theories in the history of science. However, we know that our theories are incomplete, but finding out what's beyond the Standard Model is difficult because it's such a successful theory. **Professor Alison Lister** and her colleagues at the University of British Columbia and around the world are poking holes in the Standard Model, towards finding a new theory that gives a more complete description of the universe.

Challenging Science's Most Successful Theory

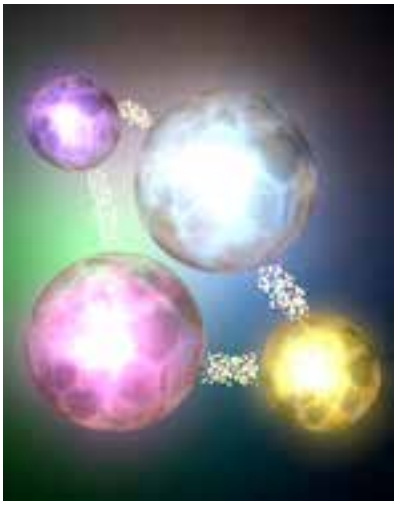
Modern physics is in a strange position. In the 20th century, our understanding of physics changed dramatically. Einstein's theories of special and general relativity provided us with deep and beautiful explanations of gravity, space, time, and the large-scale structure of the universe. Meanwhile, the emergence of quantum mechanics reshaped our understanding of the smallest structures in the universe.

The combination of these two revolutions in our understanding led to the development of Quantum Field Theory. When combined with ground-breaking experimental results, Quantum Field Theory led to the establishment of the Standard Model of Particle Physics. The Standard Model is a theory centred around the universe being made up of a small number of fundamental particles, forces and rules governing their interactions – which is the foundation of our modern understanding of physics.

The Standard Model has made testable predictions that have been verified with unprecedented accuracy. However, it is also fundamentally incompatible with general relativity, and neither are complete theories on their own.

Further, the standard model cannot explain why there is matter in the universe. Each particle of matter has a complementary anti-particle, which is identical in seemingly every way to its corresponding particle but with an opposite electric charge. When a matter particle collides with its antiparticle, the two are annihilated into pure energy. This seeming symmetry between matter and antimatter clashes with the universe we see, which is filled with stars, gas, and planets, all made of matter. The Standard Model suggests matter and antimatter should have been produced in equal amounts in the early universe, but this would lead to a universe without matter or antimatter.

Professor Alison Lister at the University of British Columbia is a world-leading experimental physicist, and an expert on the Standard Model. The goal of

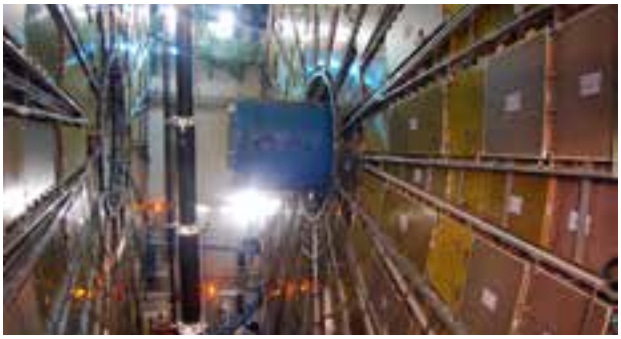


her research is to break it, towards developing a more complete picture of the universe.

Beyond the Standard Model

As Professor Lister argues, our best way to get past the Standard Model and find a deeper theory of physics is to 'poke holes' in it: find situations where the theory makes inaccurate predictions. This gives us clues about what's wrong about the Standard Model, and also lets us constrain the theories that might replace it. These are called 'Beyond the

Aerial photo of the LHC



The ATLAS detector in the LHC

Standard Model', or BSM, theories, and there are many of them, such as theories with extra space-time dimensions. Figuring out the most promising replacement is hard, precisely because the current Standard Model is so successful, and it's difficult to devise experiments to distinguish which theory is most accurate.

Professor Lister is tackling this problem on two fronts: precision measurement and searching for particles beyond the Standard Model.

Crucial to both of these goals is the Large Hadron Collider (LHC). The LHC is a particle accelerator, located in a 27-kilometre ring-shaped tunnel that lies between France and Switzerland. This enormous contraption allows physicists to accelerate protons to near light-speed and collide them. This process is so energetic that it lets physicists probe the limits of our theories, exploring conditions that simulate extreme high-energy interactions or the first few nanoseconds after the Big Bang. At four different points around the tunnel, the beams are brought into collision in the middle of giant detectors, packed full of incredibly sensitive devices, giving physicists a window into what exactly happens after such high-energy particles collide.

Experiments at the LHC have confirmed many Standard Model predictions, most notably discovering the Higgs Boson. The Higgs Boson is a particle that was predicted by physicists developing the Standard Model in the 1970s, but wasn't experimentally detected until 2012 at the LHC.

However, many researchers have actually been hoping to be surprised by the LHC experiments, for the reasons described above: it would give us tantalising insights into the theories beyond the Standard Model. So far, the results have been accurately predicted by the Standard Model, but Professor Lister hopes to change this.

Precision Measurements on Top

By measuring experimental data, physicists can identify deviations between theory and reality. However, these deviations can sometimes be miniscule. Therefore, Professor Lister and her colleagues focus on extremely precise measurements, so that they can find these tiny deviations.

The team's primary object of study for these precision measurements are particles called 'top quarks'. Quarks are a type of fundamental particle that, along with leptons such as electrons, are the basis of all atomic matter in the universe. Quarks come in six varieties, or 'flavours', evocatively named 'up', 'down', 'charm', ' strange', 'top', and 'bottom'.

Up and down quarks are the most common, as they constitute the protons and neutrons within atoms. The other four flavours are more exotic, and Professor Lister studies the heaviest of these: top quarks. While up and down quarks weigh far less than a hydrogen atom, each top quark has the mass of an atom of gold.

Because of their large mass, top quarks are only created in extreme environments such as high-energy collisions. These do occur naturally, for example when high energy cosmic rays strike particles in the Earth's atmosphere, but they cannot be analysed well there. Instead, physicists use the LHC to generate top quarks to measure their properties and see what happens when they decay.

Top quarks have an incredibly short lifespan, decaying on average just half a trillionth of a trillionth of a second after they're created. You might think this makes it hard to study top quarks, but it's actually a blessing in disguise, as it means they are the only quark that can be observed directly. Their short lifespan means that they don't have time to combine with other quarks, like the other five quarks very quickly do. This means top quarks are the only quark that can be studied in isolation.

Further, mass is fundamentally linked to the Higgs field and thus the Higgs Boson. The Higgs field is crucial to our understanding of how and why particles have the masses they do. Thus, the large mass of top quarks renders them directly detectable and allows physicists to indirectly study the properties of the Higgs Boson, providing more opportunities to test the Standard Model and constrain the theories beyond it.

Professor Lister pioneered this type of precision measurement experiment at the LHC using ATLAS. Her goal is to improve the sensitivity and precision of the data, by improving our accuracy

of correctly identifying top quarks, and correcting for impacts of the detector on the data. She has been using and developing machine-learning tools for over a decade to improve our sensitivity to BSM physics.

Searching for Long-Lived Particles

The second focus of Professor Lister's work is searching for so-called long-lived particles.

As we discussed earlier, we know the Standard Model isn't a complete theory. One area we know it falls short is explaining 'dark matter'.

When astrophysicists began studying distant galaxies, they discovered a strange phenomenon: they appeared to spin faster than their apparent mass should permit. Stars at the edge of a galaxy seemed to orbit so fast that they should have been thrown out of the galaxy, and yet their orbits are stable. This suggests that galaxies contain much more mass than we can see, anchoring these stars in orbit.

Astronomers posed many explanations and refined their measurements and theories, but still failed to find a conventional source for this invisible mass. Most physicists now agree that some kind of exotic matter must contribute this mass. This is labelled dark matter, since it seemingly doesn't interact with light.

However, the Standard Model doesn't propose any particle that fits this description. This means that understanding and explaining dark matter will be crucial to developing theories beyond the Standard Model.

Professor Lister and her colleagues have approached this by trying to synthesise potential 'dark matter candidates' using the LHC. If they can produce and detect a particle that matches the properties expected for dark matter, this would be the first ever direct detection of something from beyond the Standard Model, kickstarting a whole new era of particle physics research.

Many theories beyond the Standard Model predict particles that might explain dark matter, but they do so in wildly different ways. Some predict a single particle, while others predict a whole 'dark sector' of currently unknown particles. Ruling these theories in or out could dramatically change our understanding of the universe, and re-prioritise global physics research.

Physicists around the world are waiting with baited breath for researchers to find flaws in the Standard Model, and no one knows whether the next big leap in our understanding of physics will come from the discovery of some new dark matter particle in the LHC, or from some tiny deviation between theory and measurement, such as in the properties of the top quark. Professor Lister and her team work on both fronts, and their research may contribute to the largest shift in our understanding of physics in a century.

Meet the researcher

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Professor Alison Lister is a world-leading experimental physicist with over two decades of experience. In 1998, she undertook her degree in Physics at the University of Oxford in the UK, before joining ETH Zurich in Switzerland for her PhD on the measurement of b-quark jet shapes at the Collider Detector at Fermilab, obtaining her doctorate in 2006. She then continued her research at the University of California at Davis, USA, and the Université de Genève in Switzerland. In 2012, she joined the University of British Columbia in Vancouver, where she now works as an Associate Professor and Canada Research Chair in particle physics, conducting ground-breaking research, supervising a host of PhD students, and lecturing on particle physics, relativity, quantum mechanics, experimental methods and more.

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THE UNIVERSITY OF BRITISH COLUMBIA

TAPERED LADS: ACQUIRING CRYOGENIC LIQUID PROPELLANTS IN DEEP SPACE

To carry out complex manoeuvres such as orbit insertion, large spacecraft on long voyages must carry tanks of liquid propellants, kept at ultra-cold temperatures. In existing designs, however, heat leaking into these tanks can form unwanted vapour bubbles in the channels required to extract their contents – which are especially difficult to remove in the microgravity environment of deep space. In their research, a team at the Southwest Research Institute presents a simple solution to this problem – through which the sides of these extraction channels are tapered, allowing vapour bubbles to escape. Results from recent microgravity testing of this technology could lead to exciting new opportunities for future space missions.

Spacecraft Propellants

Future human-tended missions to Mars and beyond will require large spacecraft to safely transport astronauts and advanced propulsion systems, which allow the vehicle to enter the orbits of planetary bodies. To carry out these complex manoeuvres, spacecraft must carry propellants in specialised tanks, and release them precisely when commanded.

The best propellants for this job are typically cryogenic fluids including hydrogen and oxygen, which exist as liquids at ultra-cold temperatures. However, since their boiling points are so close to absolute zero, it is virtually impossible to keep these propellants in a fully liquid state throughout their long voyages. Instead, vapour must be separated from liquid inside the tank.

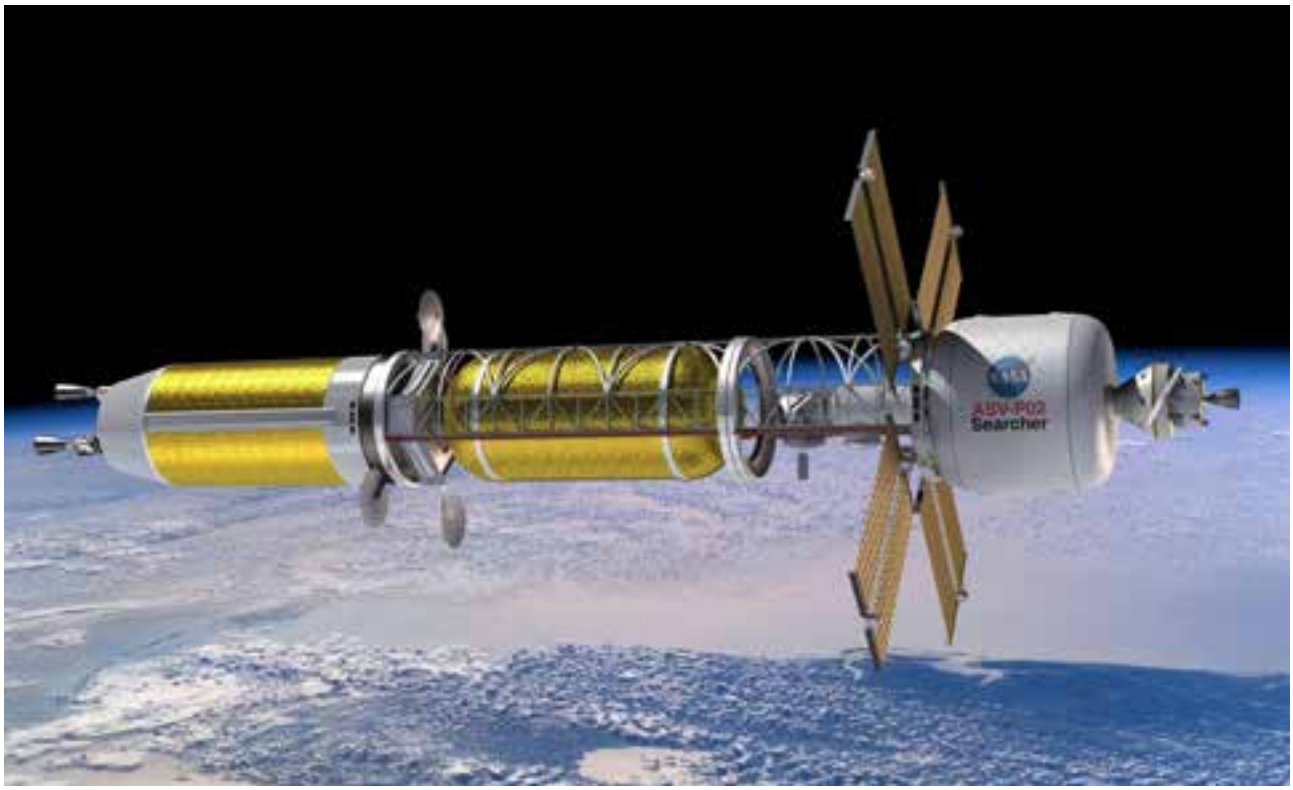
To achieve this separation in the low-gravity environment of deep space, researchers are beginning to explore the potential for innovative storage tank designs, featuring specialised internals named Liquid Acquisition Devices (LADs). To separate pure liquid propellants from vapour, LADs incorporate fine porous screens. Through the effects of surface tension, these screens allow liquid only to pass straight through, while blocking any bubbles of vapour.

As it runs parallel to the walls of a propellant container, a LAD's screen forms a narrow channel. Ideally, this narrow space will always be full of liquid propellant, which can be extracted from a tap at the bottom of the tank. This relatively simple design has been used for decades in spacecraft, including the Space Shuttle, with storable propellants such as hydrazine. LADs also have promising potential for use in future long-term space missions. However, before they can be implemented in cryogenic propellant tanks, LAD designs still have one major barrier to overcome.

CREDIT: NASA/Joel Kowsky

Introducing a Tapered Channel

Over the course of a spaceflight that spans multiple years, it would be virtually impossible to keep ultra-cold propellant tanks perfectly insulated from the outside environment. As heat inevitably leaks into the chamber, it will be transferred directly to the cryogenic



CREDIT: NASA

liquid extracted by its LADs – causing unwanted bubbles of vapour to form inside the channels.

These bubbles can damage rocket engines and make propellant transfers between tanks less efficient. However, they are difficult to remove in current LAD designs, especially in microgravity environments. Currently, this would require spacecraft to either carry out costly thrusting manoeuvres to force the bubbles out of the channels, or implement expensive and bulky systems for actively separating vapour from fluid inside the tank.

So far, this shortcoming has prevented the use of LADs in cryogenic propellant systems, despite their otherwise promising capabilities. In a recent study, a team at Southwest Research Institute introduces a simple modification to the LAD design, which could prove to enable the management of internal vapour bubbles. Their concept is based on a tapered channel – with a cross-section that gradually widens out towards the top of the tank.

As vapour bubbles form inside the channel, they are subject to interfacial forces due to surface tension. Here, vapour bubbles can be squeezed through narrow spaces as they seek to minimise their surface energy, without any assistance from external forces, such as gravity.

In this case, vapour bubbles are forced to move towards the wider end of the channel at the top of the tank, where they can be extracted out of the LAD – far away from the propellant extraction point at the bottom. This passive pumping technique is particularly promising, as it could be readily integrated into existing LAD designs without adding costly mass to the technology.

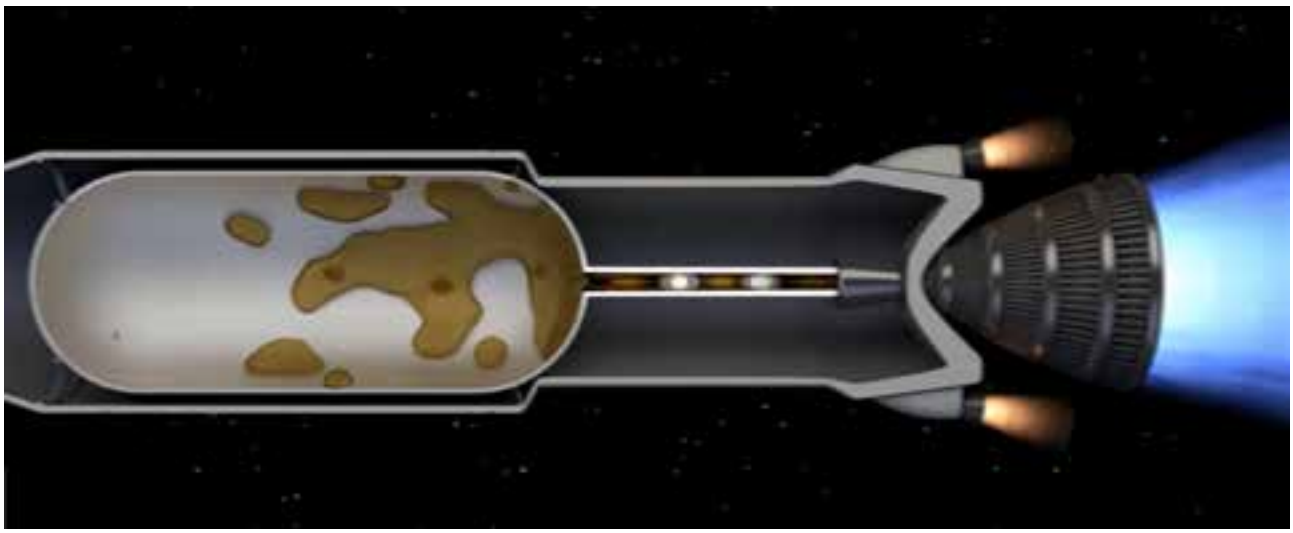
Experiments Aboard New Shepard

To validate their approach, Southwest Research Institute would first need to test its performance in a high-quality microgravity environment for an extended period. While they didn't have access to the microgravity environment of outer space, they could simulate these conditions with the help of Blue Origin's New Shepard spacecraft. This reusable rocket is designed to take both space tourists and research payloads to the edge of space.

New Shepard takes off vertically, and once the capsule separates from the rocket, it follows a parabolic suborbital trajectory for three minutes. During this time, gravity is temporarily counteracted by the capsule's acceleration under freefall, producing the zero-gravity conditions required by the team. In 2019, the researchers carried out their first tests aboard New Shepard.

Their apparatus featured simple, liquid-filled channels containing a single air bubble, which widened out towards the bottom. The team also varied several properties of this setup across different channels – including liquid composition, channel taper angle, and surface roughness.

As New Shepard ascended, the team observed that the bubbles in each tube remained at the top of the channels, under



CREDIT: NASA

acceleration and gravity driven buoyant forces. But under the spaceship's simulated microgravity, some bubbles were driven towards the wide end of the channel by surface tension, just as they had predicted. All the same, this motion varied widely between tubes with differing parameters.

Lessons for Future Designs

Through their initial tests, the Southwest Research Institute team learned several important lessons about how bubbles can be ejected more efficiently from a tapered LAD, which they explored through two subsequent flights in 2020 and 2021. Based on their results, they could then establish a set of guidelines as to how LADs with tapered channels can best be implemented.

Firstly, the researchers noted that the displaced liquid in front of the bubble's path needed some way to flow freely to the narrow end of the channel, without passing around the bubble directly – which would increase its drag. To do this, they incorporated a 'liquid return passage' into the LAD design, which allowed liquid to bypass the bubble without affecting its motion.

In addition, the team found that the composition of the liquid itself had a strong influence on the bubble's motion. In particular, they observed that water proved too viscous, and stuck to the sides of the channel too readily – preventing the bubbles from moving during microgravity. The bubbles moved far more easily when surrounded by liquids that better simulate cryogenic fluid properties including isopropanol and HFE-7000 – which exhibit lower viscosity and surface tension when compared to water.

The team also noted some effects which had surprisingly little influence of the bubbles' motions. These included the roughness of the LAD's inner surface, and the shattering of bubbles inside the tubes – which occurred when New Shepard's capsule separated from its propulsion stage, after main engine cut-off.

Modelling Different Influences

Across these flight tests, the Southwest Research Institute team also examined how bubble motions varied as they changed the tapering angles in their LADs. While channels with more tapering may be more suitable for smaller propellant tanks, they would take up far too much space within larger tanks. To overcome this issue, the researchers suggest that LADs could be designed with taper angles that vary along the lengths of their channels – limiting their widths at the top of propellant tanks.

Based on the results of their flight tests, the team next developed an analytical model to predict the movement of bubbles through tapered LAD channels. Their model could account for the influence of all the different factors they had tested so far – predicting bubble velocities to within just 0.2 mm per second in ground-based experiments. The researchers will now aim to further validate their model's predictions using the data gathered from these flight tests and seek opportunities to test this technology in future long-duration cryogenic experiments in space.

Applying LADs in Long-term Spaceflight

Ultimately, the team at the Southwest Research Institute hopes that the insights they have gathered so far could soon enable tapered LADs to be implemented in cryogenic propellant tanks. Their work could help engineers to specifically tailor the design to factors including tank size and propellant composition, allowing them to passively remove internal bubbles – even in the microgravity of deep space.

In turn, their simple innovation could lead to new spacecraft designs, which could greatly reduce the required propellant tank size and complexity, thus satisfying one of the critical technology needs for enabling future crewed missions to Mars and beyond.

Meet the researcher

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Kevin R. Supak is a program manager in the Flow Characterization Section, Southwest Research Institute (SwRI). Here, he manages research programs across a wide array of industries, including oil and gas, aerospace, and water purification technologies. He currently oversees the technical execution of projects, including the testing of liquid-gas separation under field realistic conditions, and studying the interaction between gas and liquid under microgravity environments. Supak also manages the Multiphase Flow Facility at SwRI, which conducts high-pressure multiphase testing for evaluating large-scale equipment and advanced sensing techniques. Before joining SwRI, Supak worked with L-3 Communications at Johnson Space Center, where he designed and constructed models for simulating fluid and thermal systems of space vehicles.

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DSCOVR: MONITORING EARTH'S CLIMATE AND THE THREAT OF THE SUN'S WEATHER

The Deep Space Climate Observatory – DSCOVR – is a satellite orbiting between the Sun and Earth at the first Sun-Earth Lagrange point. The primary mission of DSCOVR is to measure the incoming solar wind conditions and provide these measurements in near-real-time, to enable space weather forecasting. DSCOVR also has instruments that can monitor Earth's climate, by measuring energy reflected and radiated from Earth, and can track levels of ozone, aerosols, clouds, vegetation and ocean properties, and more. Led by scientists **Dr Adam Szabo** and **Dr Alexander Marshak**, the project is a joint mission between National Oceanic and Atmospheric Administration (NOAA), the US Air Force, and NASA.

The Deep Space Climate Observatory

The Deep Space Climate Observatory – DSCOVR – was launched atop a SpaceX Falcon 9 rocket in early 2015. Its primary mission is to monitor the Sun's weather near Earth. Its secondary objective is to provide novel Earth observations from a unique vantage point. To achieve these goals, the project is a collaboration between three major agencies.

The Air Force provided the launch vehicle, NOAA operates the spacecraft and its solar weather forecasting instrumentation, and NASA built the spacecraft itself, as well as operating the two Earth-facing science instruments.

Monitoring Earth's climate requires a good view of Earth, of course. On the other hand, tracking solar weather is most useful when the satellite is closer to the Sun than the Earth is, so that it can act as an early warning system. However, if the satellite is closer to the Sun than Earth is, its orbit will be faster and it will not remain in the vicinity of Earth.

To resolve this conflict, DSCOVR travelled 1.5 million kilometres to a special point between the Earth and the Sun, called the first Sun-Earth Lagrange point, or L1. Here, the gravity from Earth and the Sun balance each other, and so the satellite can remain near the Sun-Earth line with few course corrections.

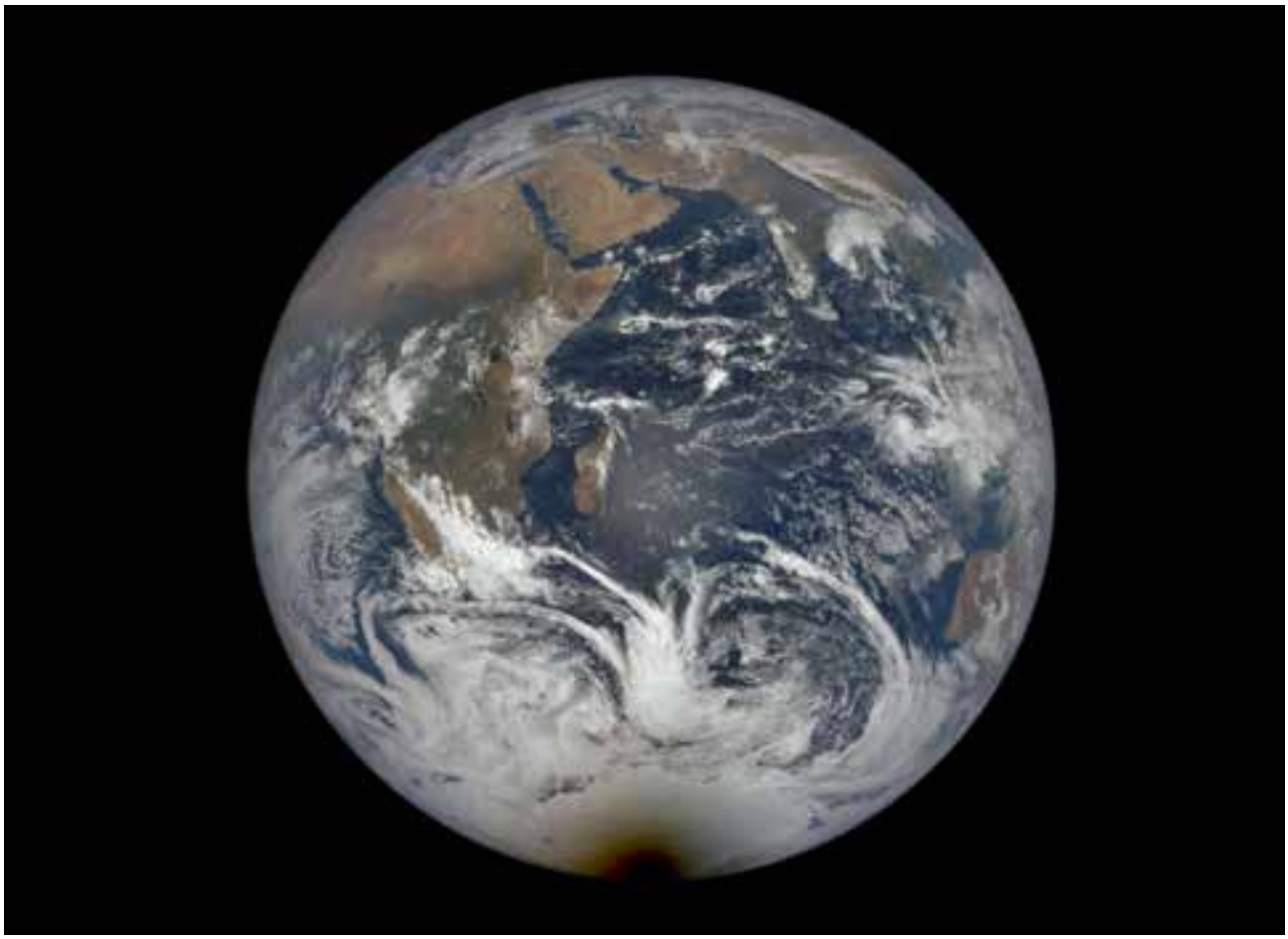
The L1 Lagrange point is perfect for space weather monitoring, as a satellite near this location can sample the incoming solar wind around 40 minutes before it reaches Earth. Thus, space weather forecasting on a 30-minute timescale is possible.

The L1 point also provides a unique vantage point for Earth science. From there, almost all of the sunlit face of Earth is visible, unlike from typical low-Earth orbits. This enables, for example, studies of how characteristics of the Earth system changes from morning through noon to evening. All of the DSCOVR images of Earth are uploaded online daily.

CREDIT: NASA/Tony Gray and Tim Powers

Monitoring the Health of Earth's Climate

DSCOVR has two Earth-facing instruments – one that looks at



On December 4th, 2021, EPIC imaged a rare total solar eclipse in Antarctica from 1 million miles away.

broad-spectrum radiation, and one that is tuned to particular frequencies of radiation from ultraviolet to near-infrared spectral ranges.

The former is NISTAR, which measures how much energy is radiated and reflected from Earth towards the critical near-sunward direction. If more energy leaves the Earth system than the amount the Sun provides, the Earth will cool over time. However, if more energy is absorbed, the Earth will warm. This is called the planet's radiation budget, and is key to tracking the progression of climate change, in both the short and long-term. The deeper understanding of Earth's radiation budget provided by NISTAR will help scientists and decision makers to devise the most effective strategies to mitigate global climate change.

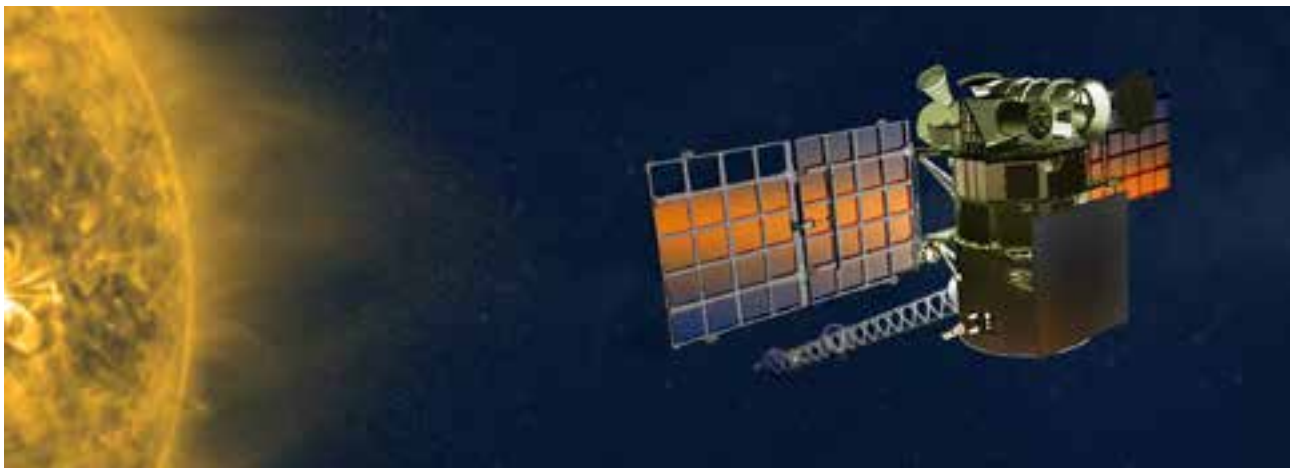
The second instrument is EPIC: the Earth Polychromatic Imaging Camera. This is a Cassegrain telescope with a 30-centimetre aperture. An aperture is the circular hole that lets light in: the larger the aperture, the more light that can enter, allowing more detail to be achieved. Cassegrain is a telescope design where light is first reflected by a concave mirror, which aims the light at a smaller convex mirror, which focuses the final image to a point.

So, how does EPIC help us monitor the climate? The air on Earth is transparent to many wavelengths – or 'colours' – of light. However, clouds, smoke, aerosols and certain molecules such as ozone can reflect certain wavelengths of light back into space, allowing them to be detected by EPIC.

EPIC is built to detect ten specific wavelength ranges of light. To do so, the telescope houses a wheel of filters. By rotating the wheel, the filter covering the sensing equipment can be switched – with each filter blocking all but a narrow range of wavelengths. Each wavelength range is chosen to detect certain molecules in the atmosphere.

For example, one filter only lets through light with a wavelength of 317.5 nanometres. This lets EPIC detect ozone, an unstable molecule containing three oxygen atoms that forms when ordinary oxygen molecules are hit by ultraviolet light or, more excitingly, by lightning. Ozone rises to the upper atmosphere and protects life on the surface by absorbing 98% of the Sun's harmful ultraviolet light.

The ozone layer can become depleted by the release of chemicals such as CFCs, used in refrigerators and propellants. As such, to monitor the 'health' of the atmosphere, EPIC keeps track of ozone levels and distributions in the atmosphere. The good news is that worldwide control and bans on the use of CFCs has slowed ozone depletion, allowing it to slowly recover.



CREDIT: NOAA

Wavelengths of light detected through the other filters onboard EPIC allow scientists to examine aerosols in the atmosphere, study clouds, and even measure the density of vegetation.

The near-infrared radiation scattered by vegetation is very strong, allowing EPIC to see green leaves even through optically thin clouds. Since EPIC sees the radiation reflected by the brightest portion of the canopy, it allows scientists to directly measure the sunlit leaf area, while also estimating how individual leaves reflect solar radiation, which offers unique diagnostic information about the biochemistry of leaves.

Glints are caused by the reflection of sunlight from highly reflective objects. Such objects include the ocean or other water surfaces, and cloud ice crystals that reflect sunlight like a mirror consisting of numerous tiny pieces. EPIC offers excellent opportunities to learn about ice clouds that cause glints.

EPIC's camera generates images of 2,048 x 2,048 pixels. To reduce the transmission time to Earth, these images (except those recording blue light) are compressed to 1,024 x 1,024 pixels – roughly the size of a standard Instagram photo. The resolution is around 10 x 10 kilometres at the centre of Earth's image, meaning that each pixel of the final image covers around 100 square kilometres of Earth's surface, which the team verified by looking at the width of the Nile and Amazon rivers.

A Warning System for Solar Activity

DSCOVR also watches the Sun, using the Plasma-Magnetometer – or PlasMag. This suite is composed of an instrument measuring the solar wind particles and a magnetometer observing the local magnetic fields. The Faraday Cup solar wind instrument detects the gale of charged particles including protons and alpha particles that are thrown from the outer layers of the Sun. Unlike the steady output of light and heat that life on Earth relies on, the solar wind is shockingly chaotic, as the intense magnetic fields within the Sun ebb, flow, and snap, energising the material to millions of degrees and launching charged particles, which flow outwards into space.

Most of this solar wind is harmless to us. Since it is made up of charged particles, the solar wind responds to magnetic fields. The molten iron in Earth's outer core generates a strong magnetic field, which deflects most of these charged particles around Earth.

In the chaotic soup of the Sun's surface and atmosphere, raging solar flares and other activities can lead to 'coronal mass ejections' or 'CMEs', where phenomenal amounts of charged particles and magnetic fields are flung from the Sun's surface. CMEs can compress Earth's magnetic field and cause havoc with our electrical grids and other infrastructure. They can also damage satellites orbiting Earth, severely disrupting our communication and navigation systems.

Luckily, very large coronal mass ejections are rare. In recent history, the most intense coronal mass ejection directed at Earth occurred in 1859. This was before the widespread use of electricity, though telegram operators were electrocuted as their cables became energised, and some even caught fire. Intense auroral displays were seen not just near the poles, but all around the world.

If such a large event occurred today, there would be widespread blackouts and permanent damage to electrical grids, which would likely cause tens of billions of dollars of damage each day in the US alone. The best way to protect against such an event is to predict them in advance and shut down or isolate electrical grids before the surge of charged particles reaches Earth. Vulnerable components on satellites can also be turned off to protect them. Thus, it is key to detect these events as early as possible, which one of DSCOVR's key aims.

A Celestial Guardian

DSCOVR is a celestial guardian, keeping a watchful eye on the star that bathes the Earth with energy, sometimes destructively so. DSCOVR is also a vital tool that will help us to ensure Earth's climate remains habitable and hospitable for future generations.

Meet the researchers

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Dr Adam Szabo is the chief of the Heliospheric Physics Laboratory at NASA, and the NASA Project Scientist for the DSCOVR mission. Dr Szabo obtained his PhD in Physics from MIT, where he focused on the solar wind flow around Uranus and Neptune for his thesis. He then took a post-doctoral research position at MIT, before accepting a National Research Council Research Associate position at the NASA/Goddard Space Flight Centre (GSFC) in 1994. Ever since, Dr Szabo has continued to work at the GSFC on a number of projects. During his career, he has authored around 100 research papers, specialising in solar wind and solar storms.

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Dr Alexander Marshak is an atmospheric scientist working in the Climate and Radiation Lab at NASA, and the Deputy Project Scientist for the DSCOVR mission. He obtained his PhD in Numerical Analysis from the Siberian Branch of the Academy of Sciences of the USSR. From 1978, he worked for 11 years at the Institute of Astrophysics and Atmospheric Physics in Estonia, before receiving an Alexander von Humboldt Fellowship to work at Göttingen University, Germany. In 1991, he joined the NASA/Goddard Space Flight Centre (GSFC). Dr Marshak has published over 170 papers in the areas of atmospheric physics, remote sensing, and shortwave radiative transfer.

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FUNDING

NASA

SHAPING GALAXY CLUSTERS WITH SUPERMASSIVE BLACK HOLES

The black holes found at the centres of most large galaxies are now found to be fundamental to galactic formation and evolution. Until recently, however, little was understood about how these massive bodies affect the behaviours of their host galaxies and beyond. Through their research, **Dr Stefi Baum** and **Dr Christopher O'Dea** at the University of Manitoba have made important strides towards untangling the many mysteries involved in this intriguing astronomical problem.

Supermassive Black Holes

Supermassive black holes sit at the centre of almost every large galaxy, including our own. These colossal bodies can be millions to billions of times larger than the black holes formed through the collapse of massive stars – making them a key part of the evolution of their host galaxies. As they draw in gas and stars from their surroundings, this material is heated to extreme temperatures, triggering a wide array of exotic physical phenomena.

Centred on supermassive black holes, active galactic nuclei are one rare group of galactic centres in which particularly interesting dynamics are known to occur. As Dr Baum explains, these structures have now fascinated astronomers for decades.

'Active galactic nuclei can be fuelled by the accretion of gas and stars, producing extremely energetic phenomenon, such as luminous hot disks of accreting gas, winds, and powerful outflows of relativistic plasma and magnetic fields,' she says. Named 'jets', these flows extend perpendicular to a galaxy's flat disk, and can reach far out into intergalactic space.

Astronomers have now uncovered a close relationship between the masses of galaxies and their central black holes – implying that both systems must somehow co-evolve under linked physical mechanisms.

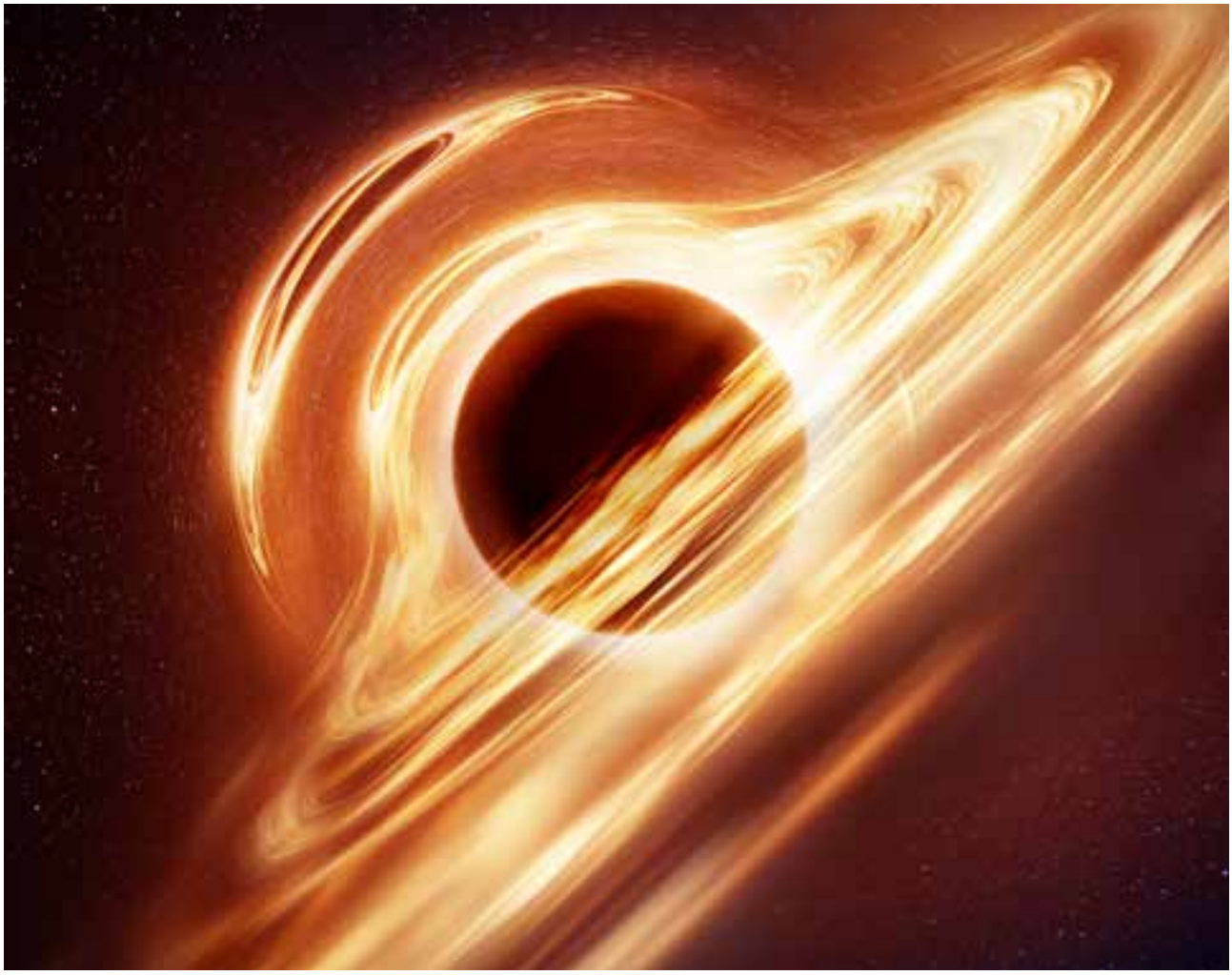
The amount of mass accreted by the central black hole is proportional to the mass that forms stars and builds the bulge mass of the galaxy. These relationships are particularly strong, given that a galaxy's star formation is extended on much larger scales than those that directly feed the black hole.

As jets emanate from an active galactic nucleus, they fundamentally alter the flow of energy throughout this region. 'The kinetic energy in the jets heats the galaxy's gas, expelling it from the central regions,' Dr Baum continues. 'This in turn influences galaxies star formation histories, mediating the relationship between host galaxy and central supermassive black hole.'

Intracluster Cooling

Among the first mysteries the team explored was the cooling of gas in the space surrounding the galaxies in a cluster – named the 'intracluster medium', or 'ICM'. According to theories at the time, astronomers understood that this gas should be losing heat by radiating X-rays – so that over time, this gas should become colder and colder, until some of it has become cold atomic or molecular gas. Yet from observations of the ICM, researchers could see that this clearly wasn't the case – leading them to question where this cold gas may be located, or if it even existed after all.

'For a while, the primary hypothesis was that somehow the cold gas was hidden,' Dr Baum recalls. 'We were among the first to realise that the radio source in the central brightest galaxy was responsible for re-supplying energy



to the ICM.' Furthermore, the structure of this central 'engine' may be heavily influenced by the galaxy's history, and the flow of material into its active galactic nucleus from the surrounding ICM.

In 2008, Dr Baum, Dr O'Dea and their colleagues uncovered further insights into how the balance of heating and cooling in galactic clusters could be better understood, by searching for cold gas and young stars. These features are often the end result of cooling interstellar gas, as the movement of particles has slowed enough for clouds of gas to collapse under their own gravity – allowing star-forming nuclear fusion to initiate.

'We were among the first to realise that careful searches for these end products would provide an important constraint on the balance of heating and cooling,' Dr Baum explains.

Diversity in Accretion

In another aspect of cluster evolution, the team delved further into the properties of the accretion disks surrounding supermassive black holes at the centres of active galactic nuclei. As it enters the black hole's surrounding environment, material is accelerated, gaining a vast amount of energy in the process. Subsequently, accretion disks partially re-emit their energy by giving off electromagnetic radiation.

Through a study published in 1995, Dr Baum and Dr O'Dea emphasised just how diverse the resulting accretion disk and jet phenomena can be with significant differences in the radio, optical, and X-ray properties. As Dr O'Dea describes, 'We were early proponents of the idea that black holes are fed with a range of mass accretion rates and this has consequences for the properties of the structure and emission from material around the active galactic nucleus.'

Drawing from these insights, the researchers subsequently explored how jets come to emanate from a small fraction of accreting supermassive black holes – giving rise to the ICM heating explored in other parts of their research. In a 2013 study, they contributed further to understanding the unique properties of these jets, paying particular attention to the transport of energy, magnetic fields, and cosmic rays.

Through their analysis, Dr Baum, Dr O'Dea and their colleagues expanded on the idea that these jets may not simply be a rare phenomenon, only ever found in a small fraction of massive galaxies. Rather, the active galactic nucleus they originate from could be a short yet important stage of galactic evolution. 'It is thought that many galaxies go through a phase where they launch radio jets,' Dr O'Dea continues. 'We have made some important contributions to understanding the properties of radio jets.'

Compact Radio Sources

In one of their most recent studies, published in 2021, the team delved further into the origins of radio jets by analysing comparable structures, which exist on far smaller scales. 'There is one small but powerful class of radio source, each a fraction of the size of a typical jet,' Dr O'Dea explains. 'We were among the first to recognise the importance of the young, compact, powerful radio sources for understanding active galactic nucleus triggering and evolution.'

A number of competing theories have been put forward to explain the origins of these structures. There is a possibility that they are young radio galaxies and will eventually evolve to produce powerful large radio sources. Alternatively, they could have been prevented from expanding outwards through interactions with dense gas in their surroundings or may only be short-lived bursts – which will disappear very soon on cosmological timescales.

By analysing each of these possibilities more closely, Dr Baum and Dr O'Dea aim to explore the fundamental basis of radio jets, and their influence over the formation and evolution of galaxies.

Triggering Star Formation

In their latest study, published in 2022, the researchers looked beyond radio jets to explore other mechanisms by which energy could be transported outwards from active galactic nuclei. While radio jets are powered by gas and stars accreting onto supermassive black holes, some of this material can contribute to dramatic bursts in star formation in the host galaxy.

This process can trigger massive stars, which only live for a few million years before exploding in dramatic supernovae – releasing vast amounts of energy in the process. 'Energy released by supernova explosions can drive gas outflows in galaxies,' Dr O'Dea describes. 'In parallel, the radiation from the bright disk of gas around the super massive black hole can also drive gaseous outflows or winds.'

Altogether, these studies have led to profound advances in astronomers' understanding of how galaxies are influenced by supermassive black holes, and the energetic radio jets produced by active galactic nuclei. In turn, the team's discoveries are enabling researchers to improve their predictive models of galactic evolution, to better account for the energetic influences of individual active galactic nuclei.

Dr Baum and Dr O'Dea now hope that their insights will contribute to a broader understanding of the dynamics that shaped the universe we observe today, and will ultimately determine how its evolution will unfold far into the future.

Meet the researchers

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Dr Stefi Baum completed her PhD in Astronomy at the University of Maryland in 1987. She joined the University of Manitoba as a Professor of Physics and Astronomy in 2014, where she worked as the Dean of the Faculty of Science until 2022. Dr Baum's main research interests include the origin and nature of galaxies and galaxy clusters, as well as the black holes at their centres. She also studies the development and deployment of astronomical instruments and missions, as well as advanced algorithms for calibration and analysis. Beyond her research, Dr Baum has developed an expertise in working at the interface between science, engineering, liberal and creative arts, business, education, and public policy.

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Dr Christopher O'Dea achieved his PhD in Astronomy at the University of Massachusetts in 1984, and has also worked as a Professor of Physics and Astronomy at the University of Manitoba since 2014. His main research interests include quasars and active galaxies, clusters of galaxies, and the intracluster medium. In particular, he focuses on how supermassive black holes influence their host galaxies, and how galaxies themselves influence the properties of their black holes in turn. Dr O'Dea uses a wide variety of techniques to develop images and spectra of these phenomena, including radio telescopes, ground-based optical telescopes, and space-based observatories.

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PROVIDING STABLE AND POWER-EFFICIENT PLASMA USING MICROWAVES

The ability to generate stable and reproducible plasma is central to many aspects of research and technology. Through his research, **Professor Michel Moisan** and his team at Université de Montréal (UdeM) explored the capabilities of various devices they patented that produce plasma columns simply and efficiently, using radiofrequency or microwaves. Applications of these devices range from the sterilisation of medical equipment, to purifying noble gases such as xenon for ion-thrusters that ensure the repositioning of communication satellites.

Generating Plasmas

Devices that can generate plasma have been continuously developed over the last few decades, particularly in welding, lasers and material processing. To generate plasma, tools developed at Université de Montréal (UdeM) take a neutral gas in a cylindrical tube, and subject it to electromagnetic 'surface waves' – typically either radiofrequency or microwaves – that run along the tube.

The electromagnetic surface waves initially accelerate a few electrons that are randomly present in the gas, which then go on to strip the outer electrons of atoms in a source gas, creating an 'avalanche' process, which culminates in a stationary fluid of electrons and ions – a plasma.

In many applications such as lighting, the generated plasma is contained inside the tube. If the process of sustaining plasma is based on electromagnetic surface waves, the tube must be transparent to radiofrequency or microwaves. It must be made from a so-called dielectric material, such as fused silica, or a ceramic that is more resistant to high temperatures and chemicals. For other applications, such as the sterilisation of medical devices, the tube must be open-ended, allowing the flowing plasma to emerge in the processing chamber.

For plasma generation to work effectively, it is crucial for power to be transferred from the radiofrequency or microwave generator to the plasma as efficiently as possible, while also ensuring that stable gas discharges can be sustained for extensive periods of time. In addition, this must be done across a broad range of operating conditions – including varying compositions and pressures in the gas. Plasma etching, for example, which is employed in fabricating the tiny circuits on computer chips, requires abrupt changes to the composition of the input gas during the manufacturing process. To operate effectively, plasma-generating devices must withstand these types of changes, without running off or substantially increasing their power requirements.

In 1991, Professor Michel Moisan and his colleague Professor Zenon Zakrzewski

first reviewed the operation principles and design of surface-wave plasma sources. Their paper has since given rise to 84 mentions in patent applications, highlighting the ubiquity of this technology in various fields.

Introducing the Surfaguide

In 2006, Professor Moisan, student Thomas Fleisch, and their colleagues at UdeM fully characterised the surfaguide

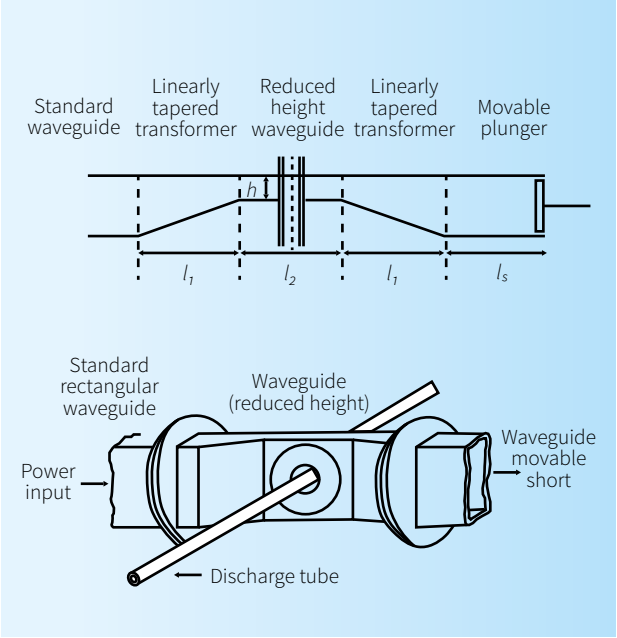

Figure 1: Schematic illustration of the surfaguide.

field applicator, and turned it into a simple, compact and efficient design that could overcome many previous challenges. The surfaguide design (Fig. 1) starts with a rectangular waveguide, where an aperture is situated through a section of the waveguide wide wall. A movable short-circuit wall, or 'plunger', allows the device to be matched with the microwave power generator.

The generated plasma column extends to both sides of the surfaguide aperture. With these features in place, the device can transfer power from microwaves to plasma at close to 100% efficiency, even across the broad range of sudden changes in operating conditions encountered during the various sequences of plasma-driven processes.

'It is possible to find surfaguide design and dimensions such that it currently runs in factories at a 6 kilowatt power level under abrupt changes in operating conditions, such as gas composition and pressure, without having to retune the plunger, ensuring constant impedance matching with the power generator,' says Professor Moisan.

Understanding Plasma Discharge Properties

It had previously been shown that, for given operating conditions, the discharge properties were independent of the specific surface wave generator used. However, it was generally believed that the properties of the propagating surface wave were directly affected by the plasma columns they generated.

This was wrong. In one of his studies, Professor Moisan revisited this assumption by observing experimentally that the electron density decreased linearly along the plasma column, and produced such a plasma along its whole length to the very end.

Upon examining this under a variety of operating conditions (gas nature and pressure, wave frequency, discharge tube inner radius), it became clear that the surface wave was sustaining the gas discharge without experiencing any interaction from the medium it created.

'This interpretation can be considered a paradigm shift, since most theorists come out with an axial distribution of electrons that curves down toward the end of the plasma column, contradicting observations,' explains Professor Moisan.

Microwaves vs Radiofrequency

Leading on from this study, Professor Moisan and his team next examined the advantages of using microwave produced plasmas, as opposed to those generated using radiofrequencies. Alongside collaborators abroad, Ganachev and Nowakowska, the researchers revealed several, unexpected and unique properties pertaining to microwave sustained discharges. 'These result from their distinct features,' explains Professor Moisan. 'For one, the microwaves only transfer energy to electrons, since the heavier positively-charged ions can't respond to rapid field oscillations occurring above 100 megahertz. Secondly, the plasmas created through microwave discharges have stationary and smaller dimensions of their "plasma sheath" layers – a region of positive ions at the vessel wall in contrast to neutrality within the whole plasma.'

Choosing between microwave and radiofrequency discharges depends on the application desired. For example, radiofrequency discharges are essential in computer chip manufacturing due to the ion bombardment that is generated in the sheath. Etching the chip substrate in this way using radiofrequency-generated plasma provides the required patterning to ensure the proper chip architecture.

On the other hand, applications including the remediation of greenhouse gases and the production of new materials are better off with microwave discharges, mainly due to the relatively higher electron density of such plasmas.

Through their analysis, Professor Moisan and his colleagues introduced a new model called the 'Concept of power per electron', which unveils several useful key features of microwave-generated plasmas. In contrast to radiofrequency plasmas, these features include the fact that almost no electron energy needs to be expended to sustain the plasma sheath, thus leading to higher electron density. Additionally, the power absorbed per electron in these discharges has been shown to adjust to compensate for the power losses – the dominant feature in this power balance.

The team also showed that absorbing power across a confined volume within the larger plasma volume increases the electric field intensity in the smaller volume, thereby offering the possibility to increase atomic excitation and ionisation.

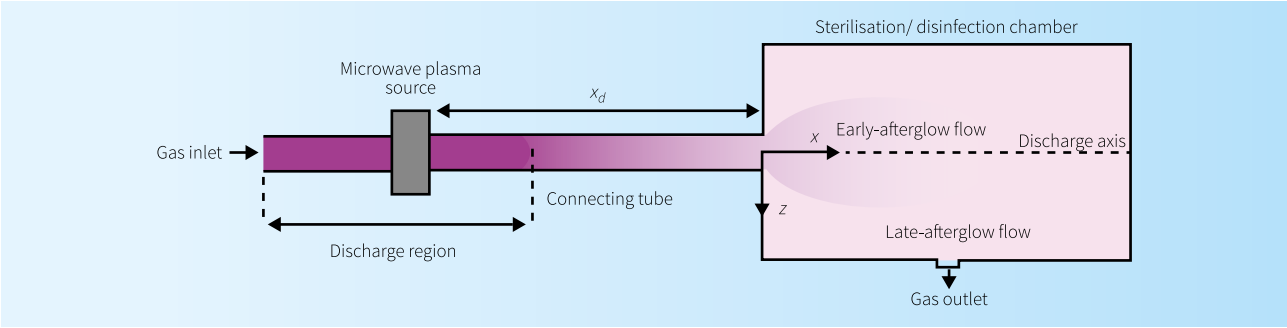

Figure 2: Representation of the discharge outflow of long-lived species as they enter the sterilisation/disinfection chamber after travelling from the microwave-plasma source.

With all of these important insights into how power is transferred through microwave-sustained discharges, researchers are now better placed to explore their applicability across a range of important scenarios.

Sterilising Medical Equipment

Among the many possible uses of the plasma columns produced by surface waves is the sterilisation of medical equipment. 'Sterilisation implies that at the most, only a single microorganism is left among initially one million,' explains Professor Moisan. With existing techniques, this often involves treating equipment with intense heat or high-energy gamma radiation, which risks damaging the apparatus. These risks can be overcome by treating equipment with ethylene oxide, but this gas is explosive, toxic, and carcinogenic. These shortcomings create strong incentives to find an alternative.

In one study, Professor Moisan and his team used the surfatron, a lower-frequency microwave field applicator than the surfaguide. They used this device to apply microwaves to an optimised mixture of nitrogen and oxygen, to generate a plasma column that emitted an intense afterglow of ultraviolet light. 'The afterglow designated the region along the column where no electric field from the surface wave is left,' says Professor Moisan.

Ultraviolet light with wavelengths of between 180 and 350 nanometres induces lesions in the DNA of microorganisms, ultimately leading to their inactivation. This light inactivates any bacteria or viruses it interacts with, as well as infectious proteins, such as the prion that causes Creutzfeldt-Jakob Disease.

The advantage of the surfatron sterilisation technique over all other plasma sterilisation systems is that it relies on the far flowing afterglow (Fig. 2). 'This means that at a long enough distance from the microwave field applicator, there are no longer any electrons in the flowing gas,' says Professor Moisan. 'Otherwise, as we demonstrated, electrons charge up on microorganisms, which are then released by an electrostatic force acting on the substrate so rapidly that they do not become inactivated, eventually contaminating the process chamber and flowing out into the outside world.'

Eliminating Greenhouse Gases and Purifying Rare Gases

In another study, Professor Moisan's team examined how plasmas could be used to remove fluorinated greenhouse gases such as CF_4 and SF_6, which can remain in the atmosphere for over 50,000 years before degrading. These two gases are used in the plasma reactors required to fabricate computer chips.

In their experiment, to avoid damage to the pumping system, the team 'drowned' these fluorinated gases in a nitrogen stream requiring plasma effluents carried in rapid nitrogen flows. 'The process, which takes place at atmospheric pressure with the addition of a few percent of oxygen, is ecologically clean and electrically very efficient when compared to burners previously used,' explains Professor Moisan. 'The surfaguide system is employed industrially in abating fab-reactor greenhouse gases as well as purifying noble gases'.

Future Opportunities

The technology of microwave plasma discharges, which has not been exploited as much as that of radiofrequency discharges, seems to offer more green and efficient prospects in plasma-driven processes. 'It provides high purity rare gases, a new approach to plasma sterilisation of medical devices and clean microelectronic fabrication facilities,' concludes Professor Moisan. 'In addition, new materials such as graphene and carbon tubes, for example, can be obtained at a higher rate with microwave plasmas when exploited according to the *Concept of power per electron*, a noteworthy model applicable to all kinds of microwave-produced discharges.'

Among the various existing field applicators, Professor Moisan states that the surfaguide is the simplest one to build and operate. 'The surfaguide has in fact become a standard laboratory tool as shown by the fact that its patented origin is no longer mentioned in publications,' he continues. 'Another potential application under development in various countries is the use of microwave plasma antennas for communication; monopole antennas can be deployed as a plasma column and transmit a message in less than a few microseconds.'

Meet the researcher

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Professor Michel Moisan achieved a Doctorat d'État (Doctor of Science) in Plasma Physics at the Université Paris-Sud (now Université Paris-Saclay) in 1971. After graduation, he was invited as Guest of the Academy of Sciences of the USSR. In mid-October 1972, he joined the Groupe de physique des plasmas at the Université de Montréal, where he currently serves as Professor Emeritus in Physics. In 2008, he also co-founded, with J. Pelletier, the International Laboratory for Plasma Technologies and Applications (LITAP), which is now an International Research Group. Professor Moisan's research interests include the use of high-frequency electromagnetic fields (radiofrequencies and microwaves) to sustain gaseous discharges, as well as the science and applications of cold gaseous plasmas up to atmospheric pressure. He has been conferred the title of Chevalier dans l'Ordre des Palmes académiques de la République Française in 2017, received the 2017 Innovation Award of the European Physical Society (Plasma Physics division) and the France-Québec Prix Adrien-Pouliot for scientific collaboration with France in 2005.

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Université de Montréal

EXPLORING HOW METALLIC GLASSES ARE FORMED FROM MOLTEN ALLOYS

Metallic glasses are extraordinary materials that can be formed by rapidly cooling certain mixtures of molten metals. Their unique properties make them extremely desirable for various technological applications. However, scientists do not fully understand the processes that drive the formation of metallic glasses, and as such, they remain difficult to design and optimise for specific purposes. **Dr Nicholas Mauro** and his team at St. Norbert College in Wisconsin have been researching metallic glasses to understand exactly how these materials form from various molten alloys. By understanding the mechanisms that lead to the formation of metallic glasses, the team's work aids in the design of new metallic glasses and enables their optimisation for specific technological applications.

Metallic Glasses

When it comes to scientific research, there are few fields that hold as much importance as the development of novel materials. Almost all emerging technology comes into being because of new and exciting materials. For instance, the discovery of silicon-based semiconductors formed the bedrock for all modern computing, while implantable medical devices owe their biocompatibility to the development of polymer coatings.

One type of novel material that has been gaining interest is so-called 'metallic glass'. The growing interest in metallic glasses is mostly due to their unique and remarkable properties, which tend to be very different to those of typical metal-based materials. These materials are often more durable than conventional metals, with a higher resistance to wear and corrosion. Some metallic glasses even soften like plastic when heated, instead of immediately melting. Like typical metals, these materials also tend to be good conductors of electricity and heat, and show interesting magnetic properties.

Metallic glasses have been investigated for their potential as strong, durable aerospace materials. In fact, NASA is currently considering their use in shielding materials for spacecraft, and in gears for planetary rovers. Their unique combination of properties mean they could also be used in electrochemical water purification systems, and as coatings for biomedical devices.

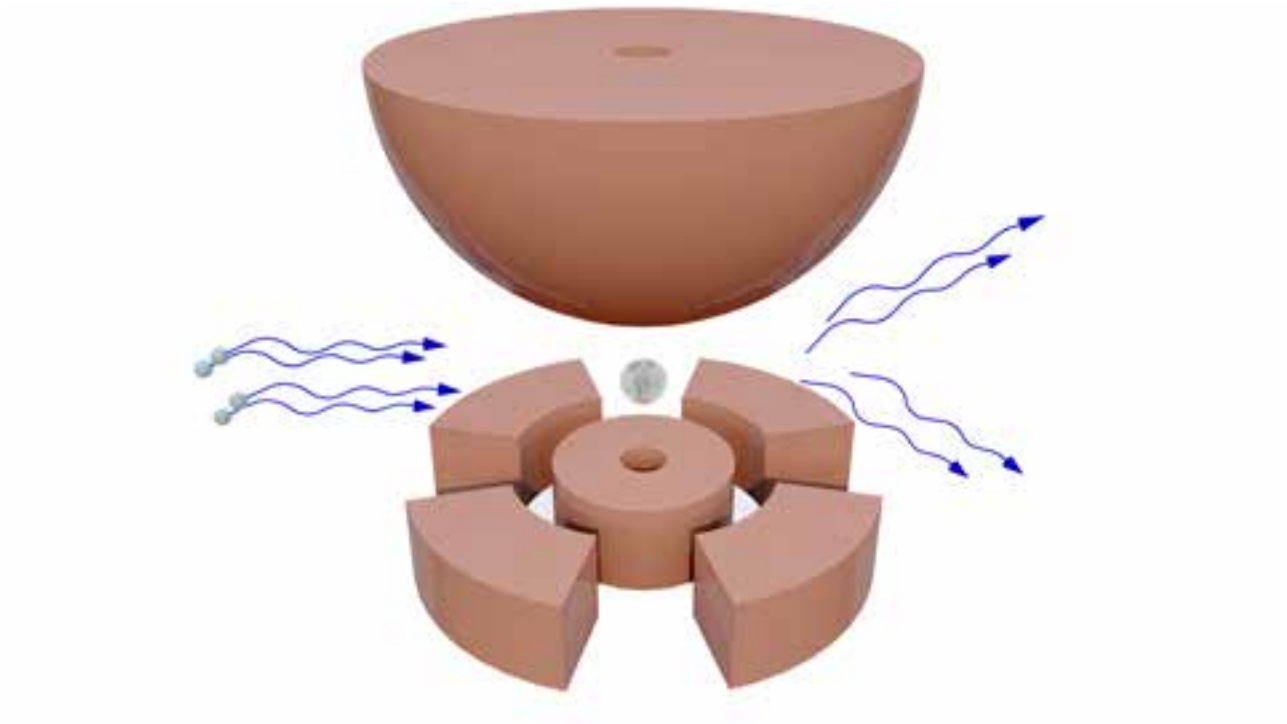
Although their useful properties have been recognised for decades, metallic glasses have not yet realised their full potential, as they still need to be optimised for their intended applications.

Amorphous vs Crystalline

The term 'glass' is often used to describe a material that has so-called 'amorphous' properties. Within a solid amorphous material, the constituent

atoms and molecules do not form a repeating pattern, and instead are arranged randomly to form a disordered structure. In the glass that makes up our windows and wine bottles, the constituent silicon dioxide molecules are arranged in this type of disordered structure. Many polymer-based materials, such as plastics, also fall into the 'amorphous' category.

On the opposite side of the coin are crystalline solids. These are defined by their well-ordered atoms and



molecules, which form a repeating three-dimensional pattern. Most metallic materials fall into this category, including iron, copper, silver, and alloys such as steel and bronze.

Although metallic glasses are made up of metal atoms, which typically form crystalline solids, they are created in an unusual way that leads to disordered, glassy structures. Because they do not have rigid internal structures, metallic glasses are often more flexible than their crystalline counterparts, meaning that they are often less likely to break under pressure.

Understanding the Solidification Process

When a molten metal cools, its constituent atoms lose their thermal energy and succumb to attractive forces with other atoms around them. As the liquid continues to cool, the metal atoms become locked into specific ordered arrangements due to these attractive forces. This solidification process balances the tendency of the atoms to form an ordered crystalline solid. Also, the increasing viscosity of the liquid tends to prevent the rearrangement of the atoms into that ordered state.

One of the key factors which can affect this process is the rate of cooling. If the molten metal is cooled rapidly enough, the atoms do not have sufficient time to arrange themselves into this ordered state, and instead become 'frozen' in place.

'Metals can form glassy, amorphous states when they are cooled rapidly enough,' explains Dr Nicholas Mauro of St. Norbert College. Through extensive research, Dr Mauro and his colleagues have been examining this process in detail.
In some of their previous research, the team analysed how the rate of cooling affected the formation of metallic glass in various alloy families. Their results highlighted the significant impact that the rate of cooling had on determining whether these materials would form amorphous or crystalline solids. Importantly, they also found that some of the alloys they studied were far more likely to form glassy solids than others.

'Very broadly, we are interested in connecting how changes in the atomic structure of liquids affects their ability to cool into different phases,' says Dr Mauro. 'In particular, we're looking for a signature in the liquid that differentiates good metallic-glass-forming liquids from poor ones.'

'Generally speaking, we don't yet understand why some metallic alloys form glasses more easily than others,' he continues. 'My work focuses on the nature of the link between the dynamics of a liquid, such as how rapidly the structure changes with temperature, and its glass-forming ability.' Achieving a deeper understanding of the glass-forming ability of different metal alloys would allow researchers to design new alloys that form metallic glasses, and then optimise them for specific technological applications.

Analysing Samples with Electrostatic Levitation

Understanding the mechanisms that drive the formation of an amorphous metal alloy can be extremely complicated. These processes are controlled by motions and interactions on atomic or sub-nanometre scales. A further complication is the fact that such processes occur on extremely rapid time scales, some of which need to be explored in one trillionth of a second. As such, Dr Mauro's team and their collaborators needed to

develop sophisticated methods that would allow them to explore processes at such small length scales and rapid time scales

Towards this aim, the researchers decided to explore two powerful techniques: 'inelastic neutron scattering' and 'high-energy x-ray scattering'. During a neutron scattering experiment, a beam of subatomic particles called neutrons is fired at a sample of a given material. Most of these neutrons pass through the empty spaces between the atomic nuclei, but some interact with the material in various ways, are scattered and detected in a chamber around the sample.

By analysing where and when the scattered neutrons hit the detector, the technique can build a picture of the positions of atoms within the material, providing detailed information about its structure. High-energy x-ray scattering operates using the same principle, but a beam of x-rays is used instead of neutrons.

In order to conduct these kinds of experiments, great care has to be taken to make sure the metallic liquid doesn't touch the walls of the container. Additionally, the experiments need to be performed in a near-perfect vacuum. These experiments are incredibly challenging, requiring careful design and execution by knowledgeable researchers and students. Facilities for conducting such experiments exist in only a few places around the world and require large-scale government support.

Dr Mauro and his team propose a solution to these issues, using the phenomenon of levitation. In this context, levitation involves suspending small amounts of metallic liquids using an electric field. Using a sophisticated computer algorithm and measuring the sample position, a charged metallic liquid can be successfully suspended in a vacuum. By levitating samples of molten alloys, Dr Mauro and his colleagues can perform scattering experiments on them, and obtain detailed information on the atomic-scale properties of the alloys as they transition from a molten state to a solid state.

This technique enables the team to gather better data than when using a conventional neutron or x-ray scattering setup, and even allows the experiments to be run by a single person, making the process far more efficient.

Dynamics of Metallic Glass Formation

Recently, Dr Mauro and his team have been exploring alloys that contain various ratios of copper, zirconium and aluminium, and how they form metallic glasses. 'These compositions were chosen because they are reported to have dramatically different glass forming-ability,' explains Dr Mauro.

After melting these three pure metals together, the team uses electrostatic levitation to suspend tiny spheres of the mixture. The team then probes the liquids with x-rays while

simultaneously cooling the samples, allowing them to explore how the atomic structure changes with temperature.

The scattering data provided the team with valuable insights into the atomic behaviours of each alloy and the mechanisms that allows each material to form a glass upon rapid cooling. The team then ran computer simulations to gain an even clearer understanding of the atomic-scale processed involved.

'This work, combined with our previous investigations linking structural evolution and viscosity across different glass-forming families suggests a deep and foundational link between the onset of structural ordering and the associated development of dynamical slow down of atomic motion and cluster formation,' explains Dr Mauro.

In essence, this means that the formation of these fascinating materials is controlled by the motions that occur on an atomic level. By understanding and controlling these motions, the team is now better equipped to create metallic glasses using a wider range of metal alloys.

Dr Mauro and his colleagues have not only demonstrated what makes metallic glasses so special, but they have also delved deep into the physical processes that enable their formation. By doing so, the team has paved the way for the design of novel metallic glasses that are optimised for their intended application. From space exploration to implantable medical devices, numerous fields stand to benefit from these remarkable materials.

Meet the researcher

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Dr Nicholas Mauro achieved his MA and PhD in Physics at Washington University. Upon completing two years of postdoctoral research at Washington University, Dr Mauro then worked as an Assistant Professor at Lawrence University, North Central College and St. Norbert College in De Pere, Wisconsin. In 2022, he was promoted to his current position as Associate Professor in the Department of Physics at St. Norbert College. Here, his research investigates the properties of various novel materials, with a particular focus on understanding the transitions between liquid and solid phases. At the same time, Dr Mauro teaches various physics classes and mentors a group of undergraduate research students. Over the years, his research has been awarded with several prestigious grants from the US National Science Foundation and NASA.

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FURTHER READING

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DEVELOPING INTELLIGENT PACKAGING SOLUTIONS TO PREVENT FOODBORNE ILLNESSES

Many of us avoid foods that contain ingredients we haven't heard of. However, many of these chemicals are beneficial because they prevent the growth of bacteria that cause foodborne illnesses. Although food quality standards have improved dramatically, outbreaks of foodborne illnesses are still common. Luckily, we have one line of defence to exploit: antibacterial food packaging. **Dr Kay Cooksey** of Clemson University is leading ground-breaking research to overcome the hurdles associated with antibacterial food packaging, bringing it one step closer to market.

Foodborne Illness

Global food systems have grown in complexity and scale to respond to increased urbanisation and population growth. These significant advances have increased food production and transportation. However, they have also exposed vulnerabilities that can radiate through a highly complex food system to cause severe food disease outbreaks.

To reduce outbreaks, governments and researchers have implemented strict and effective food safety measures and practices. Although our standards have significantly improved, bacteria including *Listeria monocytogenes* and *E. coli* still cause thousands of illnesses and hundreds of deaths in the US alone each year.

Antimicrobial Packaging

Antimicrobial packaging could serve as an additional measure to enhance food safety. Also called 'active' or 'intelligent' packaging, such materials have received considerable attention as the demand for high-quality food products with an extended shelf-life increases.

Intelligent packaging can be created by blending antimicrobial chemicals into the packaging material, or by coating a layer of such chemicals onto package surfaces. Additionally, some solutions involve sealing food in a package containing a protective gas. In response to growing consumer demand for sustainable packaging, many researchers are developing antimicrobial coatings derived from natural sources that can be applied to bio-based packages.

Intelligent packaging may seem like a no-brainer, but adoption of these technologies on a commercial scale faces several challenges. First, many of these chemicals remain mired in regulatory backlogs for years. Additionally, every substance must be extensively studied to determine whether it affects the flavour of the food. In some cases, these chemicals are only effective for short periods of time.

Most antimicrobial coatings for food packaging have only been tested in the lab. Now, we have an urgent need to test these coatings on a larger scale to assess their safety and effectiveness.

Dr Kay Cooksey of Clemson University has been at the forefront of intelligent packaging research for many years. 'My research can be described as mainly focusing on food packaging that impacts food safety and quality,' she explains. 'The food industry does a fantastic job in maintaining safety before the food goes in the package, but the idea of having a package that provides additional protection through the active release of an antimicrobial agent could provide another hurdle for spoilage and pathogenic bacteria to overcome.'

Nisin and Turkey Bologna

Nisin is an antibiotic produced by fermenting strains of the lactic acid bacterium, Lactococcus lactis. Nisin works by binding to the cell membranes of other bacteria and disrupting cellular chemistry. It is of the first antibiotics recognised for its potential in food preservation, and has been studied since the early 1950s.

Nisin shows excellent promise to combat *Listeria monocytogenes*, the bacteria responsible for Listeriosis, the third leading cause of death from foodborne illness in the US. *Listeria monocytogenes* is pervasive – found in soil, drains, water, and even on people. This harmful strain of bacteria is linked to deli meats such as salami, mortadella, and prosciutto. Though nisin is often used in processed cheese, it is still not used in deli meats.

Dr Cooksey has studied nisin in her lab for decades. In 2005, she determined the minimum level of nisin needed to inhibit the growth of *Listeria monocytogenes*. In the same study, her lab reported an effective packaging coating solution for nisin.

More recently, in a 2022 study, Dr Cooksey and her colleagues developed a food-safe coating formulation that can slowly release nisin, increasing the amount of time the antibiotic remains effective.

As part of this study, the research team inoculated turkey bologna deli meat with *Listeria monocytogenes*. They then took a sample of the meat and sealed it in a pouch with their coating solution. They found that nisin, when coated in an bio-based material called pectin, is food safe and colourless.

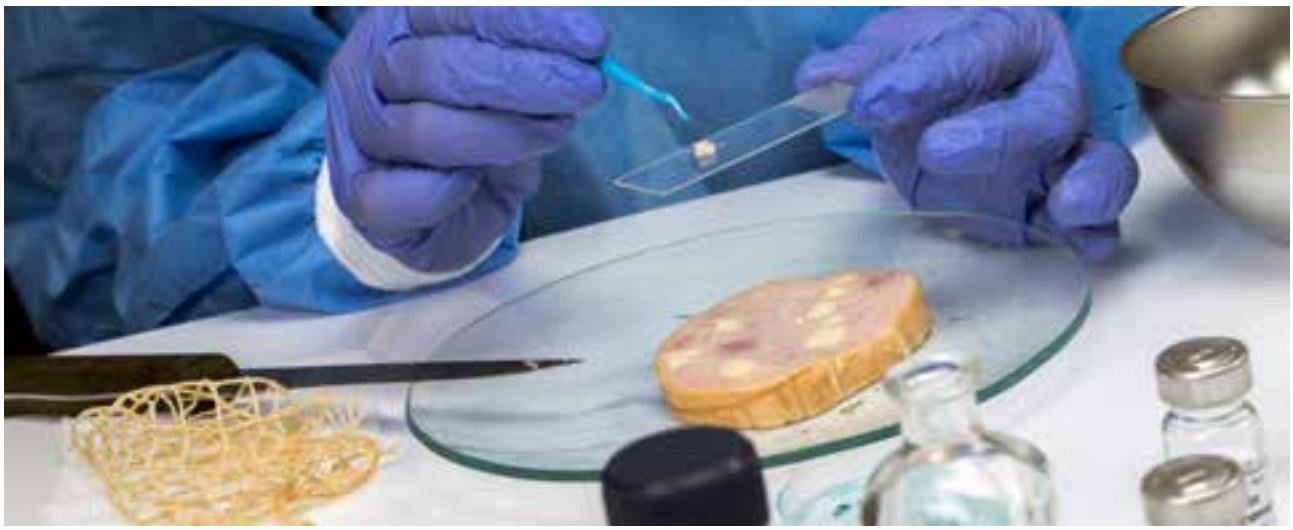
Notably, the nisin coating significantly reduced the concentration of *Listeria monocytogenes* in the turkey bologna when compared with a control. These results suggest that the nisin and pectin combination could provide valuable defence against this harmful strain of bacteria in deli meat. However, Dr Cooksey stresses that 'more testing on a wider variety of meats is needed to provide further evidence of the film's effectiveness.'

Chitin and Chitosan

Chitin, a substance that forms a major part of crustacean shells and insect exoskeletons, contains many reactive components that can readily destroy microbial cell walls. Like nisin, chitin and its derivative chitosan both show promise in combating *Listeria monocytogenes*. Chitosan can be synthesised by removing 'acetyl' chemical groups from chitin, in a process known as 'deacetylation'. However, it is impossible to completely deacetylate chitin to form pure chitosan.

In the early 2000s, Dr Cooksey and her lab evaluated the microbial effects of chitosan solutions with different percentages of deacetylation. Dr Cooksey found that all of the solutions – from 90% to 80% deacetylation – effectively reduced *Listeria monocytogenes* in a solution.

Chitosan is biodegradable, making it an attractive option for sustainable food packaging materials. However, it is sensitive to changes in pH and cannot easily diffuse through



solid materials. Luckily, Dr Cooksey has continued research into chitosan and has mentored several graduate students studying its properties to develop solutions that will enable us to use chitosan commercially. In 2013, for example, Dr Cooksey and her graduate student Scott Hartley compared the effectiveness of chitosan packaging methods in reducing *Listeria monocytogenes* in hot dogs.

Chlorine Dioxide to Protect Fresh Produce

Fresh produce forms an important part of a healthy diet, but many fruits, vegetables, meats and cheeses can suffer from bruising and mould. One solution is to create a protective atmosphere around food products within their packages, such as gaseous chlorine dioxide. Today, chlorine dioxide is used on fresh agricultural products to preserve food quality, supress bacterial and fungal growth, and decrease the risk of foodborne illness.

Most commonly, producers add chlorine dioxide sachets into the package, which release the gas gradually over time. However, Dr Cooksey recognised that these methods could lead to concentration gradients within the package, resulting in an uneven treatment of the produce. Her team confirmed this speculation in pilot experiments with strawberries, whose results showed that berries close to the sachet were exposed to large doses of chlorine dioxide compared with berries further from the package.

'Currently I am working with chlorine dioxide as a gaseous vapor for in-package and bulk treatment of fresh produce such as strawberries and tomatoes,' says Dr Cooksey. 'This technology shows great promise.'

In a 2022 study, Dr Cooksey definitively modelled how temperature, humidity, package shape and sachet characteristics can influence the distribution of chlorine dioxide gas at the strawberry surfaces. Unsurprisingly, the team found that the product size and humidity influenced how the gas diffused from the sachet. For example, larger strawberries had less space between them, decreasing airflow around the fruits and leading to unequal gas diffusion throughout the package. On the other hand, the temperature did not affect the diffusion rate, which surprised the researchers.

With these insights, Dr Cooksey and her colleagues improved their understanding of which variables influence chlorine dioxide distribution in packages of strawberries. The team hypothesised that by increasing space between the products and creating channels within the package, the gas would diffuse more evenly.

Then, the researchers designed a widget that would increase airflow and facilitate more effective gas distribution across the surfaces of fruits. The device contains holes on its surface to allow more gas to escape as the distance of the widget from the chlorine dioxide source increases. Data from the team's experiments showed that the widget increased the concentration of chlorine dioxide that reached the top and bottom of the package.

The team's widget is not intended to be a market-ready product, mainly because it would lead to increased plastic use in an already plastic-heavy strawberry supply chain. But the researchers write that they 'hope that insights from the widget's improved performance can be used as a proof of concept to guide package systems with built-in functionality optimised for gas distribution.'

Promoting Resiliency to Reduce Disease

Overall, Dr Cooksey's research will bring intelligent packaging solutions one step closer to reality, helping fresh produce to last longer, improving sustainability and reducing the spread of foodborne illnesses. Extending product shelf life will undoubtedly have cascading effects to improve consumer health, reduce retailer expense, and protect the environment. Most importantly, intelligent packaging will add one more obstacle in the path of harmful bacteria, adding resiliency to our global food production systems.

Meet the researcher

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Dr Kay Cooksey received her PhD in Food and Nutrition from the University of Illinois at Urbana-Champaign in 1992. Prior to her PhD, she received her BS in Food Science from Purdue University and MS in Industrial Mechanical Technology with Packaging emphasis from Indiana State University. After she completed her PhD, Dr Cooksey held a postdoc at Purdue University where she worked on a NASA project that involved developing safe foods for long-term space missions. Then, she joined the faculty at University of Wisconsin-Stout in the Industrial Mechanical Technology Department where she taught courses in Packaging Technology. In 1998 she continued her career in academia at Clemson University in South Carolina as part of the Packaging Sciences faculty. Dr Cooksey is currently Professor and the Cryovac Endowed Chair in the Department of Food, Nutrition and Packaging Sciences. A prolific and well-respected researcher, Dr Cooksey has received dozens of awards, including the coveted Reister-Davis Lifetime Achievement Award from the Institute of Food Technologists.

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CLEMSON UNIVERSITY

MICROPLASTICS: SOLUTIONS FOR A PERSISTENT POLLUTANT

Plastics have revolutionised human existence. Medicine, technology, agriculture and construction all rely on highly durable plastic materials. However, the enduring legacy of plastics extends far beyond our cities and towns. Everywhere we look, from the deepest parts of the oceans to alpine glaciers, we find tiny fragments called microplastics. Recently, the collaborative research centre, 'CRC 1357 Microplastic', at the University of Bayreuth was granted a second funding phase by the German Science Foundation, to continue their intensive research into microplastics. The CRC 1357 team studies the formation and behaviour of microplastics in the environment and their long-term effects on soils, plants, organisms, and ecosystem processes. Through their research, the University of Bayreuth will be able to contribute to ground-breaking recommendations for policy-makers, industry and society.

Plastics: A Double-Edged Sword

Look around your home, office, or town, and you'll quickly find something made of plastic. These materials are ubiquitous for a reason; their reliable stability under various environmental conditions makes them highly effective materials in diverse industries, including medicine, construction, manufacturing, textiles, food packaging, and technology. Plus, they are lightweight and have lower production costs than other materials, such as glass or metal.

In the 1970s, commodity plastic use soared, with single-use, disposable items dominating most industries. Quickly, plastics overfilled landfills and littering made it hard to ignore the glaring effects of our plastic addiction. Now, we find plastic everywhere: in raindrops, on mountain tops, on the bottom of lakes and oceans, and even in our bodies.

Plastic production continues to increase rapidly, with global production currently at 400 million metric tons per year. A large portion of plastics are recycled or incinerated. However, another large portion ends up in landfills, easily leaking into the environment. Their durability means that most plastics that have ended up in the environment are still there, creating a whole suite of ecological and environmental issues that go far beyond the nasty aesthetics of littering. Once plastic is in the environment, it fragments because of solar radiation and mechanical, chemical or biological stress. The resulting small particles are called microplastics.

Specifically, the term microplastics refers to the fragments of plastics smaller than 5 mm. Microplastics exhibit different behaviours in the environment compared to the material they originated from. For example,

one common type of microplastic is sloughed from car tires as they abrade against roads.

If current production continues, roughly 12 billion tons of plastic waste will accumulate in natural environments and landfills by 2050. Once these plastics enter the environment and become microplastics, they can have severe consequences for wildlife and ecosystems. Though their small size makes their impacts less visually obvious, microplastics can be easily ingested and enter terrestrial and aquatic food webs.

This ubiquitous contamination of the environment, and the associated risks to ecosystems and human health, have attracted much public attention. Yet, our knowledge of how microplastics form and migrate between ecosystems is still rudimentary. We also don't understand how persistent microplastic pollution affects various organisms, including humans, in aquatic and terrestrial habitats and how these impacts alter essential ecosystem processes. Worryingly, many scientists believe that we are outside of the safe operating space, since the annual production of plastic is increasing at a pace that outstrips our global capacity for monitoring. This dangerous combination of ignorance and ubiquity caused the G7 summit to classify plastic pollution as a 'top emerging global issue'.

However, solving the problem is not as simple as cutting ourselves off. Though our overproduction and reliance on plastics have caused various issues, plastics often play a central role in environmentally friendly actions. For example, the blades of wind turbines are typically made from lightweight epoxy plastic. Plus, without plastics, we wouldn't have smartphones or even computers. Thus, research focused on microplastic pollution will need to be paired with innovative studies creating new types of plastics that have high stability yet are easier to recycle and are environmentally friendly.

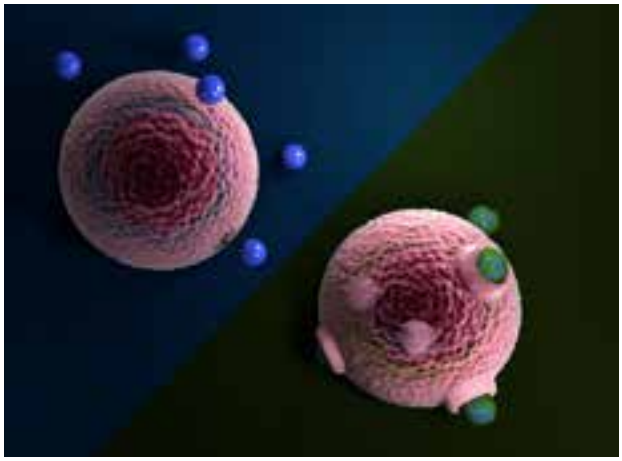
Fortunately, some of the world's top researchers have begun to tackle some of our pervasive knowledge gaps in microplastics, and are beginning to develop novel solutions. Led by Professor Christian Laforsch and Professor Andreas Greiner, the CRC 1357 Microplastics group at the University of Bayreuth in Germany stands out for its interdisciplinary approach to studying microplastic pollution.

Starting from model systems and moving towards more complex and realistic systems, researchers from CRC 1357 investigate the physical, chemical, and biological processes that microplastics experience in the environment. Their interdisciplinary expertise ranges from understanding how plastic affects single cells to tracking how these particles migrate through global ecosystems. The researchers use their comprehensive knowledge of the entire lifecycle of a microplastic to develop novel materials that help us wean from our plastic addiction.

Biological Interactions with Microplastic

Given their small size, many organisms – including humans – unwittingly ingest microplastics. Once microplastics are ingested, they come in contact with cells and tissues, causing inflammation, cell death and can move into the circulatory system.

The chemical and physical properties of microplastic particles play an important role in their interaction with cells and tissues. For example, one study by CRC 1357 PhD students Anja Ramsperger, Julia Jasinski and Matthias Völkl showed that supposedly identical microplastic particles from different commercial manufacturers were fundamentally different in their properties, leading to varying cell responses. Hence, the team showed that the characteristics of plastic particles have a crucial impact on the hazard assessment of microplastics.



Macrophages ingesting microplastic particles coated by an eco-corona (blue with green coating), whereas plain plastic particles (clear blue) are refused.

As well as their varying characteristics, other factors can alter the biological interactions with microplastic. For example, microplastic particles exposed to the environment can become coated with biomolecules – forming a so-called eco-corona. With this knowledge, Anja Ramsperger wondered whether such a coating would affect the cellular internalisation compared to pristine microplastic particles.

Together with an interdisciplinary team within CRC 1357, she investigated whether macrophages would more easily internalise microplastic particles exposed to fresh or saltwater. Macrophages are some of the first responders– specialised cells that engulf foreign matter. Macrophage ingestion might be a key route for microplastics to get into tissues, where they may cause severe damage.

Their results showed that such exposed microplastic particles attached to and became internalised by the cells approximately ten times more often than pristine microplastic particles. Furthermore, when the team investigated the microplastics closer, they found that the particles exposed to fresh or saltwater had irregular surfaces, indicating that a coating of biomolecules had attached to the microplastic. In contrast, the pristine microplastic had plain surfaces.

The results of the CRC 1357 researchers demonstrate that the characteristics of plastics and environmental coatings play important roles in the interaction of microplastics with cells and tissues. Both findings are critical first steps for future studies predicting how ingested plastics might affect human health and wildlife.

Movement of Microplastics

Microplastics take diverse routes that transport them into ecosystems and remote habitats worldwide. To understand the distribution of microplastics, we need to map these transportation routes. Large bodies of water, such as lakes and oceans, are commonly considered sinks where microplastics can accumulate over time. On the other hand, atmospheric winds can transport and redistribute microplastics. Most researchers believe that the transportation of microplastics from bodies of water to the atmosphere is a vital migration pathway for microplastic particles. However, this pathway has largely been understudied.

CRC 1357 PhD student Mortiz Lehmann used high-end 3D models to investigate one potential pathway for microplastic transport between the atmosphere and aquatic systems: raindrops. When raindrops come in contact with a body of water, the impact site shoots upward at very high speeds and can eject more than a hundred droplets into the air. Because the surfaces of most bodies of water contain microplastics, the team wondered whether raindrop impacts could act as a possible pathway for microplastic transition from water to the atmosphere.

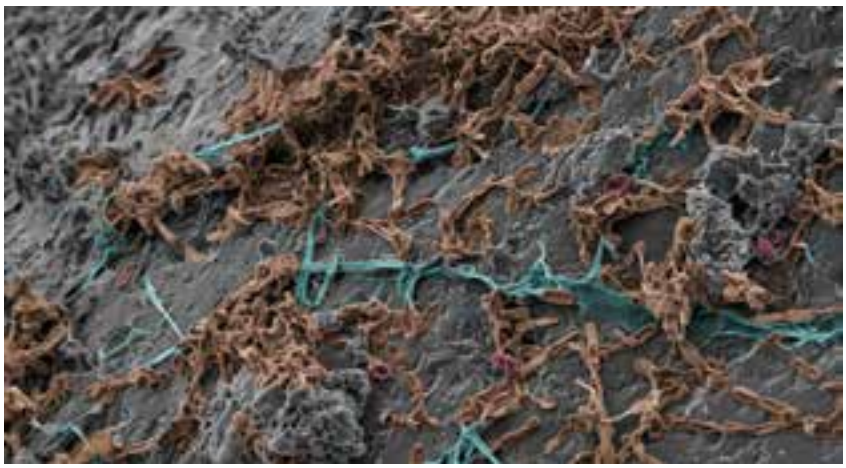
To test this idea, the researchers improved and optimised a state-of-the-art simulation tool to model fluid flow. They simulated more than 1600 impacts of raindrops at different angles, drop diameters, and randomly placed microplastics in various positions on the water surface. They paired these simulations with laboratory experiments demonstrating microplastic particles in splash droplets.

Based on the team's observations, typical precipitation and wind data, they estimated the number of microplastic particles that transitioned from the global oceans into the atmosphere annually due to raindrop impacts. The final numbers were staggering: up to a hundred trillion particles transition from global oceans into the atmosphere every year.

This study conclusively showed that microplastic particle transport occurs across the water-air interface during raindrop impacts on the sea surface. In addition, a significant proportion of these microplastic particles are probably quickly removed from the atmosphere by falling raindrops. However, changes in the particle surface may occur due to the forces involved in the transition process. Nevertheless, the study shows that interface transitions and atmospheric transportation have a strong potential to redistribute large amounts of microplastics.

Stress Accelerates Microplastic Degradation

Currently, we only have a basic understanding of how larger pieces of plastic degrade into smaller microplastic particles. Furthermore, we still lack detailed mechanistic knowledge of the processes driving plastic degradation, especially in relation to fragmentation under various environmental conditions. However, without clearly understanding this, we cannot create reliable risk assessments for the better storage and disposal of plastics. This further hampers the development of new environmentally friendly polymers.



'Fungal Plastisphere Jungle' on spherical microplastic buried for 5 months in soil of a landfill in Germany (blue: hyphae, orange: blastospores and pseudohyphae (yeasts), red: conidia/spores). The image was produced by Gerasimos Gkoutselis PhD within the CRC 1357 Microplastic and Ulrich Mansfeld from the Keylab Electron Microscopy of the University of Bayreuth.

Alongside an interdisciplinary team, CRC 1357 PhD students Nora Meides, Teresa Menzel, and Anika Mauel used accelerated weathering to simulate the environmental degradation of three polymers commonly found as waste in the environment: polystyrene (PS), low-density polyethylene (LDPE), and polypropylene (PE). They used various analytical techniques combined with simulations to mimic this long-term degradation on a reasonable time scale. The main mechanisms were degradation by UV radiation and mechanical forces through natural stress, such as the movement of seawater. Their findings verified that degradation from large plastic pieces into microplastic occurs over multiple stages, resulting in a multitude of tiny fragments.

In the first stage, the surface layer of the plastic is broken down by solar radiation and reactions with oxygen. Then in stage two, microcracks are formed, weakening the polymer structure and accelerating its degradation. During fragmentation, the molecular chains of the polymer become shorter and more branched. In this way, one polystyrene particle generates 500 small daughter particles in just 1.5 years of outdoor weathering. In one of their papers, the team provides details on both stages that can be used to predict the degradation of other common plastics. Notably, the researchers show that the speed and extent of degradation largely depend on the intensity of the applied stresses. For example, plastics exposed to solar radiation will degrade much more slowly when not additionally exposed to mechanical stress. Compared to LDPE and polypropylene, this process is relatively slow for polystyrene.

The fragmentation of LDPE and polypropylene involves a third step not reached by polystyrene within the observed time frame. Owing to a more considerable fragmentation, leading to the formation of smaller particles, LDPE and polypropylene tend to aggregate due to the changing surface characteristics. These secondary particles rarely occur as individuals in the environment, as they adhere to other particles.

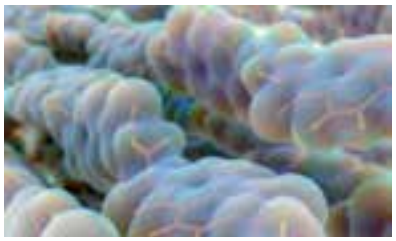
A second profound difference is the speed of the break-up processes in stage 2. The disintegration of LDPE and polypropylene proceeds via surface fragmentation, significantly increasing the particle production rate. For example, from one polypropylene particle, 100,000 small daughter particles are generated in 2 years, and 14,000 small daughter particles are released from one LDPE particle within 1.5 years of outdoor weathering in Central Europe. These fragmentation rates are several orders of magnitude higher than those observed for polystyrene.

Although the studies used laboratory-controlled weathering conditions, the team's results can be extrapolated to better understand microplastic degradation in natural environments. Their results, specifically those relating to polypropylene degradation, highlight the immense secondary pollution resulting from inadequate waste disposal. Other factors beyond the environmental stresses selected for these studies, such as temperature, microbes, oxygen, and salinity, will also affect microplastic degradation and the lifetime of microplastics in the environment. In contrast, additives such as UV stabilisers will extend the lifetime of polymers.

The Plastisphere

A poorly understood aspect of plastic pollution is the interaction between plastics and microbes. The surface of plastic waste provides an ideal environment for microbes to colonise, forming diverse communities called 'biofilms', otherwise known as the 'plastisphere'. Often, microplastics attract microbial communities that are different from those found in the immediate surrounding environment. In this way, the plastisphere formed by microplastics represents a unique microhabitat, which can have unprecedented effects on local ecosystems. Moreover, as microplastics can influence the soil microbial community, they can strongly impact ecosystem services such as carbon sequestration.

The role of microplastics as a reservoir for harmful microbes has long been proposed, but has received comparatively little research attention. Many knowledge gaps exist concerning microbes and fungi that accumulate on plastics in terrestrial environments. PhD students Gerasimos Gkoutselis and Stephan Rohrbach, a mycologist and microbiologist working together within CRC 1357, provided the first in-depth



Biodegradable polymer molecules.

insights into the development of fungal communities in the soil plastisphere. They also evaluated whether microplastics can harbour pathogenic fungi in terrestrial habitats. Specifically, they assessed plastisphere microbial communities in a German dump and fungal communities in the topsoil of five sites in Siaya, Western Kenya. Their sites included two landfills, a marketplace, a roadside, and a courtyard.

The team found rich fungal communities, showing that microplastics can be regarded as microhabitats for a diversity of fungi. The plastics only contained 76% of the total fungal species in the surrounding soil, suggesting that plastic selects for certain fungi, likely those with certain adhesive abilities, resulting in an uneven and artificial community.

Remarkably, many of the fungi the researchers found were pathogens of plants and animals, with the most dominant species being opportunistic human pathogens. In their survey, the team found the fungus *Fusarium oxysporum*, which causes severe eye infections in humans, and *Rhodotorula mucilaginosa*, a species that can thrive in the bloodstream and has been shown to cause serious blood infections in hospital patients. Furthermore, they found a selective accumulation of yeasts that cause invasive lung and brain infections.

This study is the first to demonstrate the direct impact of plastic pollution on the accumulation of soil-borne pathogens, with several ecological and epidemiological implications. Most notably, given that plastic is omnipresent worldwide, microplastics likely open new infection routes that increase disease risk for wildlife, livestock, and humans. Furthermore, microplastic can shape the microbial community of soil, and thus its capacity for necessary ecosystem services.

Solutions

Within CRC 1357, various projects are underway to create new types of materials that achieve the ideal balance between durability and environmental degradability.

In one project, CRC 1357 researchers and international colleagues considered whether natural tree gum waste could be modified to form stable, biodegradable materials. In its natural state, tree gum waste is weak and brittle. However, when the researchers chemically modified the material, the resulting material was not only considerably stronger but biodegraded within 28 days. The material also had excellent antibacterial properties – an essential feature that determines the shelf life of packaged goods. This novel research highlights that this material could be used in the environmental and food packaging industries.

Along with experimenting with natural waste products, CRC 1357 researchers have also conducted various studies in which they changed the chemical properties of many plastics, such that they degrade more quickly without leaving any persistent microplastics. Currently, biodegradable packaging conflicts with the need for high-performing packaging materials to reduce food waste, although they can help prevent plastic accumulation in our environment.

Combining biodegradable polymers with vermiculite nanosheets can accelerate the degradation rate and improve the barrier properties of the polymers. Using this approach, CRC 1357 PhD students Volodymyr Dudko and Renee Timmins created materials that are not only more degradable than existing biodegradable polymers, but also have similar durability and affordability to non-biodegradable plastics.

Finally, CRC 1357 PhD student Elmar Sehl created a new co-polyester platform, which provides an ideal balance between mechanical properties and fast hydrolysis. These materials also showed rapid enzymatic degradation. With PhD student Renee Timmins, he applied a thin nanocomposite coating to such a substrate, leading to a material with a drastically increased oxygen barrier, while maintaining the good mechanical properties and optimum composting time of less than eight weeks.

Moving Forward

In general, research on microplastics is still a growing field. Thanks to research done at CRC 1357, we understand that the complex effects of microplastics depend on the properties of the particles, their interactions with microorganisms, and how they move between ecosystems.

The urgency of the plastic crisis has also led to innovative experiments, with new products being developed that aim to strike the perfect balance between durability and sustainability. Collectively, our society faces an immediate challenge: coming to terms with the fact that we need plastics, while reducing our dependence on single-use plastics designed for convenience. Along with behavioural changes, we must invest in groups such as CRC 1357, whose interdisciplinary and thorough research is critical to improving how we deal with valuable plastic materials, towards a safer and more sustainable way of life.

As the group's Spokesperson Professor Laforsch concludes: 'Only through cooperation between the various scientific field is it possible to approach the challenges that this topic poses to science. Plastics are a valuable material, and our task is to enable a future-oriented and ecologically sustainable use.'

Meet the researchers

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Professor Christian Laforsch was awarded his PhD in Biology from Ludwig-Maximilians-Universität (LMU) Munich in 2003. Upon graduating, he worked at several prestigious universities, including the University of Leipzig, Lancaster University and LMU. In 2012, he started his current role as a Professor and Chair of Animal Ecology at the University of Bayreuth. Here, Professor Laforsch is the Spokesperson for the collaborative research centre, CRC 1357 Microplastics and speaker of the International Training Network LimnoPlast. His research focuses on aquatic ecology and evolutionary ecology, particularly how organisms adapt to a changing environment through phenotypic plasticity.

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SFB MIKROPLASTIK

UNIVERSITÄT BAYREUTH

CAR TALK: ACTIVE PHASED ARRAY ANTENNA SYSTEM DESIGN FOR VEHICLE-TO-EVERYTHING COMMUNICATION

Information exchange between vehicles and the world around them offers many exciting possibilities. Drivers could be provided with real-time information on the speed and behaviour of other cars around them, live updates from city infrastructure to vehicles could improve traffic flow, and vehicle-to-mobile communication interfaces could warn pedestrians of busy crossings. However, such advances require a strong and stable signal to ensure reliable and effective communication. **Dr Jeong-Wook Kim** from the Korea Advanced Institute of Science and Technology has developed a new design for vehicle communication antennas, improving the ability of individual vehicles to exchange information with the world around them.

Communication and Connectivity

The design of modern vehicles inherently requires the potential for communication with the world. Perhaps the most obvious example is that of communication between the vehicle and the driver, and so we have the dashboard conveying information about speed, fuel level and potential technical issues. Between vehicles, however, the only options currently available are flashing headlights and sounding the horn.

As communication technology improves, researchers and engineers are keen to develop stable ways in which vehicles can exchange more information with the world around them. This information exchange could update drivers on situations they are yet to encounter or aspects of a situation they are unable to see. The potential benefits of this inter-vehicle communication are far-reaching. Communication between vehicles could warn road users of sudden changes in another vehicle's speed or direction potentially concealed in a driver's blind spot, or the approach of emergency vehicles.

Whilst our existing satnav systems can update traffic conditions and suggest alternative routes – thus providing some of this functionality, greater information exchange between vehicles would increase their accuracy and provide immediate real-time updates. Vehicles could also communicate with static devices incorporated into city infrastructures. Communication between road users and these infrastructure-based devices could be used by traffic controllers to reduce congestion and improve the flow of traffic around the city.

This concept of a vehicle that communicates information not only with the driver but also with other connected devices around it is called vehicle-to-everything communication. Vehicle-to-everything is a similar idea to the Internet of things, whereby Internet-connected devices gather information from and update each other. An example of this would be a household heating system being controlled from your mobile device.

The major difference between vehicle-to-everything and the Internet of things is that communication between vehicles is made difficult by the speeds involved. Many of the component parts of the network are moving relative to each other, and the internet connection is not always reliable or accessible. Therefore, for vehicle-to-everything communication to work effectively, vehicles must be equipped with a form of emitter and receiver system. This antenna system must be able to send signals out from the moving vehicle it is mounted on, whilst also receiving signals from a myriad of other sources which may also be moving.

For an effective vehicle-to-everything system, the antenna must be mounted on a vehicle without affecting its overall design and efficiency, and also reliably exchange information with other devices in the vicinity. To meet this challenge, Dr Jeong-Wook Kim from the Korea Institute of Science and Technology has developed an antenna array specifically to meet the requirements of vehicle-to-everything communication.

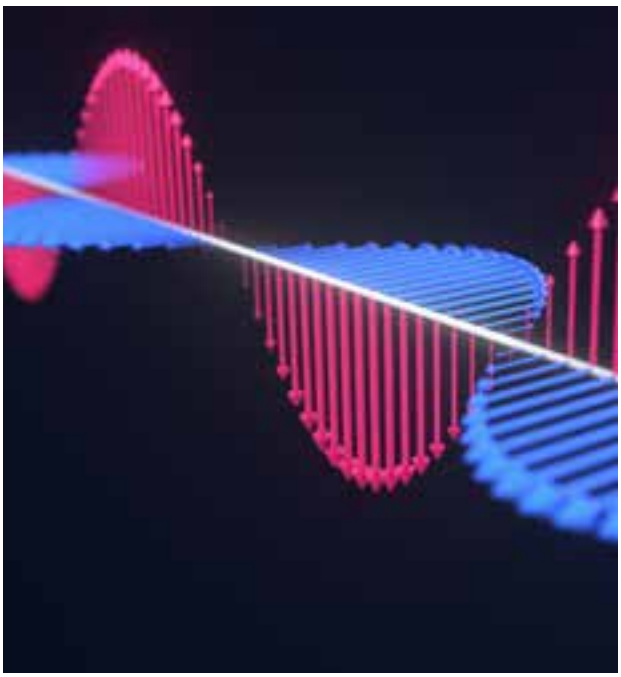
What Makes a Good Vehicle-to-Everything Antenna?

There are three major considerations that Dr Kim had to satisfy in his mission to construct a viable vehicle-to-everything antenna system. First, the physical size and shape of the antenna needed to be suitable for mounting on a vehicle. A large TV-style antenna might be great at receiving and sending signals but is unsuitable for mounting on a vehicle. If the antenna protrudes too much from the surface of the vehicle it will decrease the aerodynamic profile, reducing fuel efficiency and running the risk of breakage under high-speed situations. Dr Kim saw that his antenna would need to have a low profile to reduce the impact on the vehicle's aerodynamics, and given that the antenna will have to operate from the power supply of the vehicle, he had to ensure it would not be overly power-hungry.

The second aspect Dr Kim had to consider was the scanning angle of the antenna. The scanning angle is the angle from which an antenna can pick up incoming signals. In the case of vehicle-to-everything antenna systems, we want as large a scanning angle as possible, as signals could be coming from any position around the vehicle, whilst also moving around relative to the vehicle. By having a large scanning angle, the vehicle can detect more incoming signals and can transmit its own information to more receivers.

This scanning angle is dependent on the half-power beam width (HPBW) of the antenna. The HPBW is the angular width of the major lobe of an antenna radiation pattern where the signal power is half its maximum value or -3 dB from the peak of the main beam. If we have a beam of radio waves from a transmitter, we measure how the signal changes as we move perpendicularly across the beam. The highest power will be directly in line with the source of the beam, and the power will decrease towards the edges of the beam. The larger the HPBW, the larger the antenna scanning angle, and so for vehicle-to-everything communication, the HPBW needs to be as large as possible.

The final aspect of antenna design that Dr Kim needed to consider was 'gain'. The gain of an antenna is the ratio of the radiation intensity in a given direction from the antenna to the radiation intensity averaged over all directions. As the gain of the antenna increases, system performance is improved. For Dr Kim's antenna, system performance was defined as how well it



turns the information in the form of an electrical signal from the vehicle into an electromagnetic wave to be sent out to other devices in the area, and how well it transforms the incoming electromagnetic wave into an electrical signal to be turned into useable information for the driver. With a high-gain antenna, a vehicle-to-everything system can send and receive signals more efficiently and communicate more effectively with the other devices around it.

System Design

To create an antenna that lies flush with the surface of the vehicle, Dr Kim began by looking into a one-side shorted patch antenna. These have a very low profile and could easily be mounted to the roof of a vehicle without affecting the aerodynamics. However, the existing square design of the one-side shorted patch antennas means that they have limited scanning range and gain, which makes them unsuitable for vehicle-to-everything systems.

The reason for the limited gain and scanning angle associated with one-side shorted patch antennas lies in their geometry. The antennas have three sides that generate magnetic currents, and the fourth side acts as a ground. The problem in the square designs lies in that the magnetic currents from the sides adjacent to the ground act at odds with one another, serving to reduce the performance of the design. Despite the inclusion of electrical 'walls' designed to reduce the impact of these currents, the square designs still suffer from reduced gain.

To create an antenna with fewer detrimental magnetic currents, Dr Kim turned to more circular designs. By using a semi-circle design, Dr Kim found he could design the magnetic currents in the antenna for high gain performance. The magnetic current is generated across the flat edge of the antenna and with the curved edge of the semi-circle being ground. Dr Kim calls this design an 'arc-shorted half elliptic element'. Dr Kim tested several curved designs ranging from a semi-circle to a flatter semi-ellipse. In testing, he found that the curved designs all had a higher frequency bandwidth than the square designs and that the gain improved as the length of the ellipse was increased.

Rather than having one large semi-ellipse antenna mounted to the vehicle, Dr Kim incorporated many smaller individual antenna elements into an antenna array (also known as a phased array). By having an array of smaller individual antennas, Dr Kim's novel design is much more powerful than a single large element. There are numerous benefits to having an antenna array over a single antenna. These benefits include an increase in overall gain and sensitivity to incoming signals, a decrease in the amount of interference and noise on the received signal, and the ability to better determine the angle an incoming signal is coming from.

This improvement is clearly shown in Dr Kim's data. A single antenna element of Dr Kim's semi-ellipse design gives a 162° scanning angle – but when many of these elements are combined into an array the scanning angle increases to 180°. By mounting several of these antenna arrays it would be relatively easy to gain full 360° coverage around the vehicle. As such, Dr Kim's final design for the antenna array incorporates 16 semi-ellipse antenna elements.

Car Networking

Dr Kim's antenna array design is a huge leap forward in achieving a working vehicle-to-everything ecosystem of vehicles. The semi-ellipse design means that Dr Kim improves gain and scanning angle while maintaining the aerodynamic profile. Using Dr Kim's antenna array design, it is very likely that we will see vehicle-to-everything capable vehicles on the roads very soon.

Meet the researcher

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Dr Jeong-Wook Kim received his BS degree in Electronics Engineering from Pusan National University (PNU), Busan, South Korea, in 2018, and MS and PhD degrees in Electrical Engineering from the Korea Advanced Institute of Science and Technology (KAIST) in 2020 and 2023, respectively. His current research interests include wireless power charging systems and adaptive current control algorithms, phased array antenna systems and beam shaping algorithms, transparent conductive material and invisible antenna design, vehicle antenna design, RADAR systems and signal processing, and EMI Shielding graphene design.

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UPGRADING SUGAR CANE MILL TO PRODUCE REFINED SUGAR: MAKING SUGAR PRODUCTION MORE EFFICIENT (PATENTED)

The sugar industry is a giant, producing hundreds of millions of tonnes of refined sugar each year. In the USA, most sugar is produced from sugarcane, but the process of growing sugarcane, milling it into raw sugar, then refining it into the product we're familiar with, is remarkably energy- and water-intensive. Dr Chung Chi Chou proposes a process to improve the efficiency of sugar production by combining the milling and refining stages in one plant, increasing profits and reducing the environmental impact of the sweet stuff.

The Sugar Rush

Sugar is ubiquitous in our modern diet. It's addictively delicious, and it also acts as a preservative, a texture modifier, a fuel for fermenting alcohol, and a flavouring and even a colouring agent. While many of us are trying to reduce the sugar in our diet due to health concerns, the demand is still enormous, and production is at an all time high of 175 million metric tonnes a year.

However, demand isn't the only constraint on production. In the USA, the sugar industry is contending with global competition, as well as the social and moral imperatives of social health and environmental protection. Thus, research and development in the sugar industry has increasingly focused on improving efficiency to maximise profits and reduce environmental impact. This includes managing energy, raw materials, water and environmental emissions.

Dr Chung Chi Chou, the principal scientist and engineer of *Dr Chou Technologies, Inc*., is trying to tackle these problems. Funded by a USDA Small Business Innovative Research award, his project focuses on a specific issue hampering efficiency: producing refined cane sugar from sugar mills without an attached refinery.

How is Sugar Produced?

Most sugar in the USA comes from a combination of imported refined sugar and American-grown sugarcane, a tall perennial grass with sucrose-rich stems. Once farmers have grown and harvested the sugarcane, a sugar mill extracts the raw sugar from the plant as a juice or syrup. This is then purified and treated with slaked lime and heat to stabilise and neutralise the syrup, as well as deactivate enzymes from the plant. This juice is then evaporated, eventually crystallising into a sticky, brown, raw sugar.

However, this requires refining before being sold to the public. First, the impure outer coating of the sugar crystals is removed by mixing the raw sugar with a heavy syrup and putting it through a centrifuge producing 'affined' (washed) raw sugar which is then dissolved into a liquid syrup. Next, phosphoric acid and calcium hydroxide are added to the phosphatation process for clarification, entrapping and absorbing impurities which then float to the top of the tank for easy removal. Alternatively, a carbonatation process involving the use of calcium hydroxide and carbon dioxide can be used for clarification.

The clarified syrup is passed through a coal or wood-based activated carbon and/or ion exchange process which absorbs and removes the remaining colour impurities. Finally, the syrup is concentrated and crystallised repeatedly in vacuums, resulting in the classic refined white sugar we're familiar with in our kitchens.

There are some efficiencies to this process. For example, the residual dry fibre from the processed sugarcane, called bagasse, is often used as a fuel or agricultural mulch rather than discarded. Molasses is another byproduct and a major constituent of brown sugar and rum. However, the process is still energy and water intensive, with the production of every single tonne of refined sugar requiring several hundred thousand litres of water for irrigation and processing, and emitting the equivalent of several hundred kilograms of CO2. Dr Chou argues that improving the efficiency of this process could improve profits while also reducing the environmental impact of sugar production.

Making Local Efficiencies

Dr Chou notes that this two-part process introduces inefficiencies as the sugar mill is often separate (and very distant) from the refinery.

For example, the milled raw sugar is evaporated and crystallised from a juice, but upon arrival at a refinery, it is re-dissolved with additional water, re-evaporated and re-crystallised into refined sugar. By eliminating the refining process and producing refined sugar directly from sugar mills, not only can additional water and energy be saved but investment in refinery equipment, operating expenses and labour can also be avoided. Of course, the elimination of refining would also reduce the transportation demand.

Dr Chou is studying American sugar production from cane and beet, comparing production in Florida, Hawaii, Louisiana, Texas, and imported sugar in order to calculate which parts of the production process produce the most water and energy saving and measure the impact of his proposal.

Crystallisation consumes around 60% of the energy. This is because the juice must undergo evaporation, which requires heating the water into steam. Water has one of the highest specific heat capacities of any substance, meaning it requires an exceptional amount of energy to heat a unit of water by 1 degree, and so the boilers, which provide steam/heat for processing, need a lot of heating oil and/or natural gas.

For comparison, in the 2016–2017 season, the heating of water for sugar production in America cost just under a third of a billion dollars, and required 40.2 petajoules of energy – equivalent to 0.8% of total American household electricity use across 2016. This mostly came from natural gas, pumping 2.2 million tonnes of carbon dioxide into the atmosphere. And, as Dr Chou points out, this only accounts for steam generation and ignores transport requirements. Elimination of sugar refineries will require the addition of updated filtration and/or clarification technologies in Cane sugar mills

So, how much energy would Dr Chou's proposal save? Altogether, he estimates this could reduce overall energy consumption by up to 50%.

Benefits to the Public

Dr Chou argues that these efficiencies wouldn't just save sugar companies money but would also benefit the public. As we've discussed, the proposed process would dramatically reduce the consumption of water and energy, as well as reduce the amount of carbon dioxide emission and other hazardous solid waste production from refineries. Overall, this is a great opportunity to decrease the environmental impact of sugar production.

Further, the adoption of this process would provide an economic alternative for producing American Food Grade sugar across the world. Currently, plantation white sugar is often produced by sulfitation in developing countries, which has negative global health and social impacts. However, Dr Chou believes that if the USA can prove that this one-step sugar process is economically viable, it may be adopted as an alternative to sulfitation, allowing high-quality sugar to be produced worldwide with a smaller environmental footprint. It goes without saying that this American-developed technology can be sold worldwide.

Dr Chou now plans to put the one-step production technique to the test, and to do so he first plans to conduct a market survey of refined cane sugar products. He will go on to verify the efficacy of the systems via an ultrafiltration membrane system, and further develop updated clarification technologies as a cheaper alternative to ultrafiltration. Finally, he intends to perform process development, scale-up, and economic analyses.

The sugar industry isn't likely to disappear any time soon, as supply and demand are both steadily increasing. Dr Chou highlights the potential improvements that could be made to sugar production, and his proposal for this breakthrough a one-step process is a great example of how the incentives in industry to maximise profit can and should be aligned with the public interest in reducing sugar production's environmental impact.

Meet the researcher

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Dr Chung Chi Chou is the president, principal scientist and engineer at Dr Chou Technologies, a corporation devoted to saving resources and preserving the environment for the next generation. Funded by a USDA Small Business Innovative Research award, Dr Chou is currently trying to optimise the refinement of cane sugar. He has served, as a consultant, over 40 international corporate clients in the world sugar industry and is co-author and co-editor of the 12th edition of the Cane Sugar Handbook and the editor of the 1st edition of the Handbook of Sugar Refining (both published by John Wiley & Sons). Throughout his career, Dr Chou has collaborated with universities across the world. He lectured at the Cane Refinery Institute at Nicholls State University in Louisiana from 1986 to 2016, served as a research/visiting /advisory professor for the South China University of Technology, China, from 1993 to 2015, and as an adjunct professor at Louisiana State University from 1993 to1997 and at Guang Xi University from 2001 to 2004. Before his retirement, he worked for formerly Domino sugar corporation for 30 years serving in various capacities, including as a research scientist, manager of process development and the director of the Technical Division. Impressively, Dr Chou has lectured in over 26 countries and published 65 papers and patents on the topic of sugar technologies and management. Dr Chou is also the founder and president of Wellbrook Foundation, Inc., a charitable organisation focusing on education since 1989. In recognition of this work, the foundation has received numerous proclamations/certificates of appreciation for community service from New York governmental agencies, and most recently, received a prestigious Acquistion International award – Best Educational Lecturing Foundation (New York, 2022).

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FUNDING

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HEALTH & MEDICINE

AN EXTREMELY CHALLENGING ENVIRONMENT: UNDERSTANDING THE MOLECULAR AND PHYSIOLOGICAL RESPONSES TO SPACE TRAVEL

Environmental stressors have an adverse impact on mammalian physiology, although biological systems are adept at evolving in response to regularly occurring stressors. However, the biological alterations resulting from less frequently encountered stressors are incompletely understood. **Dr Dawn Bowles** and her colleagues at Duke University Medical School are conducting experiments into the effects of the space environment on astronauts to further our understanding of the impacts of this extremely challenging environment.

Space: A Multitude of Complex Stressors

Astronauts, in their quest to explore and unravel the enigmatic entities that exist beyond Earth's orbit, are increasingly confronting environments in which a wide range of complex environmental pressures, including microgravity and exposure to high levels of radiation, are par for the course.

To better understand the multitude of stressors experienced by astronauts, Dr Dawn Bowles and her colleagues in the Department of Surgery at Duke University Medical School, North Carolina, USA, have collaborated with a team at the National Aeronautics and Space Administration (NASA) to investigate the effect of such extreme environments on the perturbation of physiological systems.

The Price of Exploration

The pivotal role that gravity plays in the maintenance of physiological integrity is becoming increasingly apparent to scientists. While it is recognized that the absence of gravity is an extreme biological stressor, the exact impact that this has on the human body remains poorly defined. Given this, it follows that an environment with minimal gravity, so-called microgravity, may pose a high risk in terms of detriment to health. Likewise, exposure to chronic levels of high-energy radiation would logically pose significant health risks. Cellular stress responses in the body are varied and depend upon the type of stressor, cell type involved, number of cells affected, and the time since exposure.

Astronauts returning from long-term space missions are susceptible to compromised immune function, decreased bone density, skeletal

degeneration, and adverse cardiac effects including shrinkage of the heart muscle. These impacts all indicate that microgravity is a cellular stressor with the potential to adversely affect human health. This has clear implications for astronauts who are exposed to microgravity during space missions, and an understanding of how microgravity influences cellular molecular processes is imperative in comprehending these deleterious effects.

What we know so far about the pathways involved in the response to microgravity has been garnered from studies of astronauts and space flight. The predominant findings of such research include the alteration of cellular development, increased cell death and deterioration, modified protein turnover, and changes in the cytoskeleton (the structure that helps cells maintain their shape and internal organization, and helps them carry out vital functions). Although these biological amendments are known to be mediated by a complex system of genetic pathways, the precise proteins and mechanisms of action involved in the microgravity stress response have not yet been fully elucidated.

To determine the effects of microgravity on molecular processes within the cellular environment, Dr Bowles and her team employed a combination of well-established laboratory techniques to quantify large numbers of proteins, study the dynamics of alterations in protein content, and examine the biological pathways and networks involved in the response of heart cells to microgravity-induced stress.

Microgravity, Big Impact

Dr Bowles and her colleagues placed rat cardiac muscle cells into simulated microgravity or normal gravity conditions for a period of 12 hours, 48 hours, or 120 hours. The team reported that, while there were no differences or slight differences in the abundance of proteins after 12 and 48 hours in either condition, there was a noticeably higher difference in protein abundance after 120 hours of simulated microgravity. The team then proceeded to determine the protein turnover rate in cardiac muscle by using a novel modification of an established cell culture technique and measuring the incorporation of labelled amino acids into newly synthesized proteins. The results showed that there was a drastic reduction in protein turnover in the microgravity environment in comparison to the normal gravity environment over time.

Next, the team identified which proteins, biological processes, cellular components, and molecular functions were most significantly impacted by microgravity. Interestingly, those gene sets linked to the production and transport of energy in tissues with limited capacity for regeneration were up-regulated in both the protein turnover and abundance data sets. Conversely, the incidence of down-regulated gene sets was related to protein production and localization within the cell.

The team went on to investigate the mechanisms by which microgravity differentially influences cytoplasmic and structural processes. The researchers ruled out damage to the cell membrane, an increased rate of cell death, and increased protein degradation as potential causes of these differences in microgravity conditions compared to normal gravity conditions.

Taken together, these results suggest that the significantly diminished protein turnover and synthesis observed is due to a direct effect of exposure to microgravity for an extended time. Furthermore, their findings indicated that the integrity of the mitochondria, the so-called energy-producing powerhouse of the cell which comprises >30% of cardiac cell volume, is retained within cardiac muscle cells in the presence of microgravitational stress. This suggests that the mitochondria of cardiac cells respond to microgravity by supporting mitochondrial protein maintenance via a mechanism that confers preferential diversion of resources towards the mitochondria to preserve global cellular viability and promote short-term survival.

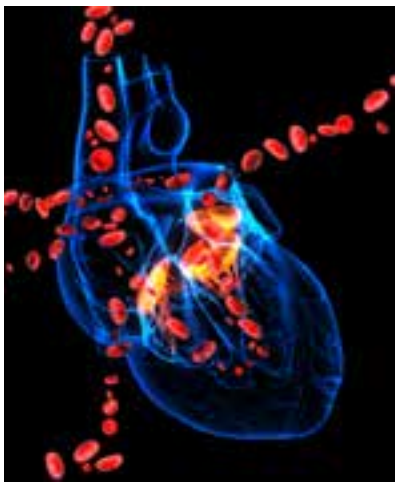
Previous findings have determined that, under favorable conditions, the specialized non-dividing cardiac cells known as cardiomyocytes maintain function by directing energy towards the maintenance of the contractile machinery and mitochondria by balancing protein synthesis and degradation.

Galactic Cosmic Rays

A unique component of the complex outer space environment is the high level of radiation comprised of Galactic Cosmic Rays (GCR). Studies involving survivors of acute high-level radiation exposure, such as nuclear accidents, have demonstrated that this is associated with a higher rate of delayed cardiovascular-related disease and death, although none of the published evidence relates specifically to space radiation. Whilst the Earth and its inhabitants are usually protected from radiation by the atmosphere, it is difficult to shield astronauts during long-term space missions, and thus they become more susceptible to serious cardiovascular health risks.

Indeed, a recent NASA study involving twins residing in space versus on Earth reported that genetic modifications and evidence of increased cardiovascular anomalies occurred only in the space-dwelling twin. However, whether this was attributable exclusively to radiation exposure remains unknown.

Accurately modelling the impact of radiation on the cardiovascular system has historically proven extremely



challenging. But now, advances in engineering and physics technology are paving the way for a more authentic simulation of the space radiation environment. Taking advantage of this novel technology, Dr Bowles and her collaborators sought to determine the possible effects of GCR on the heart. Male mice of an age equivalent to a 34-year-old human being were exposed to a single dose of GCR and monitored over the course of one year for alterations in cardiovascular function using screening processes which mimicked routine assessment conditions. The team discovered that cardiac structure and function in GCR-exposed subjects were significantly altered when compared to non-irradiated controls or those exposed to other high-energy particles, although the physiological relevance of these changes was unclear.

The performance of the heart (cardiac contractile function) was assessed in mice one year post-exposure, and Dr Bowles and her team reported that those exposed to GCR demonstrated significantly lower function, increased vascular resistance, and increased arterial stiffness than the control subjects. Rather interestingly, despite these findings, GCR exposure did not confer an increase in mortality rates, blood pressure, or weight compared to controls when assessed at the one year mark. However, histological evaluation of cardiac tissues from GCR-exposed mice revealed increased cell degeneration, fragmentation, death, and a distorted cellular structure, suggesting long-term damage to the tissues of the heart following exposure to high-level radiation, which appears similar to that commonly seen in human congestive heart failure.

Dr Bowles has recently provided new molecular data indicating that mitochondria may be perturbed in these mice. This raises the question of what happens when you look at both effects simultaneously. Now, Dr Bowles are her team are doing exactly that – examining the combined effects of space radiation and microgravity.

The Mouse PAD

Alongside this work, in 2020 Dr Bowles and her colleagues described their establishment of a repository of over 5,000 tissues from mice exposed to space radiation. Importantly, the mouse Processing Aid Device (Mouse PAD) streamlines the preparation of materials, tissue collection, and tissue processing for research purposes. As stated by the researchers, the Mouse PAD is affordable, easy to use and produces high-quality, consistent results. It can also be easily adapted by other scientists who wish to establish their own unique biorepositories for research.

The Final Frontier

Dr Bowles and her colleagues are driving forward research aiming to explore the final frontier. Her fascinating studies have greatly contributed to the fundamental understanding of the response of heart cells to microgravity stress by using a novel application of an established laboratory method to successfully identify protein turnover rates whilst simultaneously monitoring protein expression changes within the cells. Furthermore, Dr Bowles and her team have demonstrated how global cellular protein turnover and synthesis is significantly reduced in cardiac cells exposed to microgravity, which is unrelated to increased cell damage, protein degradation, or cell death, and which may explain the mechanism via which heart muscle shrinkage in astronauts occurs. Moreover, the discovery that microgravity affects the entire cell equally and at the same time suggests that this particular stressor may induce an as-yet unreported cellular stress response.

The superbly executed research led by Dr Bowles also resulted in the discovery that astronauts exposed to GCR may suffer damage to vascular and cardiac tissues long after exposure, which may predispose them to conditions such as congestive heart failure.

Further studies to improve our understanding of the coordinated cellular response, the pathways involved in the body's response, and physiological alterations emerging in response to stressors unique to the space environment will undoubtedly aid in the preparation of astronauts prior to extensive and far-reaching space missions. Work is already underway in Dr Bowles' laboratory, showing an increasingly broad and holistic approach towards understanding the complex stressors experienced by astronauts.

This ground-breaking research will increase our understanding of the adverse biological effects of space travel and aid in developing risk models to ensure improved safety during and after explorations of life beyond our aerosphere.

Meet the researcher

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Dr Dawn Bowles completed her PhD in Microbiology at Louisiana State University in 1999. After completing a postdoctoral position at the University of North Carolina, she took up several roles at Duke University Medical Center, where she is currently Assistant Professor in Surgery. Her extensive research spans the broad fields of medical genetics, cardiology, microbiology, molecular biology, surgery, and virology, and she has published prolifically in these fields with almost 100 peer-reviewed papers to date. She is the recipient of significant funding from prestigious award bodies, including the National Institutes of Health and NASA (National Aeronautics and Space Administration).

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DukeHealth

FAMILY INTEGRATED CARE: A TRANSFORMATIVE MODEL SUPPORTING PARENTING IN NEONATAL INTENSIVE CARE UNITS

Staying in neonatal intensive care units is extremely difficult, not only for the babies requiring specialist care but also for their parents. **Dr Karel O'Brien** from the University of Toronto is part of a wider community of scientists who have devoted their careers to studying the benefits of family-centred models in neonatal units. This vital work is improving the physical and psychological outcomes for families involved in this critical but challenging and stressful process.

Admissions to Neonatal Intensive Care Units

Babies who experience problems at birth and need special care are often admitted to neonatal intensive care units. This is especially common for children born prematurely. One in twelve live births in Canada are premature, meaning that the infant is born at less than 37 weeks gestation.

While a necessary intervention for the survival of premature infants, the neonatal intensive care unit is a complex and demanding environment. Premature infants are vulnerable to infection and poor nutrition, for example, and often undergo painful procedures. The neonatal intensive care unit often also creates a physical and emotional barrier between infants and their parents at a critical time for the development of parent–infant relationships.

Implications of Premature Birth for Brain Development

If born prematurely, infants face higher chances of neurodevelopmental disorders. While many escape serious conditions such as cerebral palsy, more subtle impacts such as deficits in attention and behavioural regulation, and psychological difficulties such as depression and anxiety, are often found throughout childhood and adulthood.

One reason for this is the underdevelopment of various structures of the brain when infants are born prematurely. Gaining less weight and head growth are clearly linked with delays in the development of structures on the outer layer of the brain. The hippocampus, which is situated deep in the brain, and the prefrontal cortex, situated at the front of the brain (and our most evolved brain structure), both play a key role in memory, thinking and emotional regulation. These structures are particularly vulnerable to the release of cortisol – the body's stress

hormone. Infants who are exposed to high levels of cortisol are known to be at risk of developing behavioural and psychological difficulties. Unfortunately, infants in neonatal intensive care experience high levels of cortisol not least due to the need for potentially traumatic and painful interventions.

As such, the biological effects of premature birth are compounded by the stress and challenges of the neonatal care environment, creating a complex

and multifactorial risk scenario for the premature infant. Undoubtedly, the disruption and stress that can occur due to neonatal intensive care present a serious cause for concern.

Impact on Parental–infant Relationships

A further critical factor is the impact of the neonatal intensive care unit on the development of the parent–infant relationship. It is well-established that parent–infant interactions play a key role in infant development and overall life trajectory.

Dr O'Brien saw the potential for increased parental interaction to help reduce the disruption and stress experienced by infants in neonatal intensive care. She explains, 'My clinical experience and research made it clear that parental engagement in care could decrease infections and improve growth. Meanwhile, other studies had shown that parental holding decreases infant pain during procedures.' Skin-to-skin contact between mother and baby, for example, promotes the release of oxytocin – known as the 'love hormone' in both and also reduces cortisol. Of particular importance to Dr O'Brien was the observation that parental interactions can help mitigate the negative impact of stress on the infant, and that developmentally responsive care from parents can help protect the developing brain.

A Transformative Model: Family Integrated Care

Family Integrated Care (FICare) is a model of neonatal care that provides a structure which supports family-centred care. Involving parents as much as possible in their newborn's care can benefit both the baby's and parents' physical and mental well-being. In FICare, parents are provided with the necessary support to adopt a more active role in their baby's care than has been typically possible, allowing them to be an active part of the wider neonatal intensive care unit care team instead of being passive observers.

Parents receive education as well as physical and psychological support to allow them to provide as much as possible of their infant's neonatal care. Nurses are recognised as the facilitator for the parents, providing the more technical aspects of care for the infant while coaching the parents in daily activities such as dressing, feeding, holding, bathing and talking to their baby. Finally, emphasis is placed on shared decision-making processes through the development of partnerships between patients, families and healthcare providers.

Initial but Promising Results

The first study to test the practicality and safety of the FICare model took place at Mount Sinai Hospital in Toronto between 2011 and 2012. Parents spent several hours a day at the neonatal intensive care unit, and during this time, they received support tools and education sessions delivered by experienced nurses and other staff such as dieticians.

Involving parents as key members of the infant's healthcare team and helping parents take on the role of primary caregiver as soon as practically possible brought many benefits. These initial results confirmed that FICare parents became less stressed and more confident and competent in caring for their newborns. Better outcomes were also found for newborns, including included increased weight gain and fewer adverse events and nosocomial (healthcare-associated) infections were

observed. Babies also spent less time in the neonatal unit and the number of re-admissions decreased.

This promising pilot work led Dr O'Brien and her team to conduct a randomised controlled trial (RCT) – an approach known as the 'gold standard' in research methodology – in Canada and Australia/New Zealand. This rigorous, international study confirmed the benefits of FICare for parents in reducing stress and anxiety, and for infants, better growth while in hospital. Furthermore, it was shown that the model of FICare could be effectively utilised across different settings, with the same positive outcomes.

Benefits for Infants Aged 18 Months and Their Families

Dr O'Brien and her colleagues then sought to explore the longer-term benefits of FICare. In this follow-up study, a large subset of parents and infants who had participated in the international RCT completed further assessments when the infants were aged 18 months.

The Infant Toddler Social Emotional Assessment was used to evaluate infant social, emotional and behavioural problems. The researchers also measured infant growth, parent–child interactions, and parental distress.

The results were incredibly encouraging. Not only did the infants who had received FICare demonstrate more positive behaviours and performance on the Infant Toddler Social Emotional Assessment, but their interactions with parents were also improved. This longer-term evidence allowed Dr O'Brien to justifiably conclude that 'Interventions supporting parents may decrease their stress and modulate the parent–infant relationship such that childhood outcomes are improved'.

In further studies, Dr O'Brien and her team examined the impact of FICare on babies born at less than 29 weeks gestation. Here, FICare infants had better scores on several scales including their motor skills and body mass index. Taken together, these results converge in supporting the integration of parents into the care of their infants.

Critical Next Steps

Dr O'Brien is committed to developing this programme of work to improve the care of preterm infants in neonatal intensive care units and beyond. She is now keen to find out whether the benefits associated with FICare will be sustained even into school age. In following up with the FICare participants, Dr O'Brien and her team want to understand the effect that FICare has on children's brain and behavioural development in the longer term, as well as on the complex dynamics between parents and infants. They are interested not only in what the final long-term consequences might be but also how exactly FICare modulates them. As such, future work will aim to unpick the underlying mechanisms of the observed benefits using innovative and rigorous research designs.

Despite recent advances in family-centred care, Dr O'Brien points out that there is still room for improvement. For example, current family-centred care includes multiple methods that vary from one unit to another. Improving the structure and unifying the methods of family-centred care could increase the effectiveness of such interventions.

Dr O'Brien's work highlights the importance of family-centred care methods in neonatal units Empowering parents to take more initiative in care at neonatal units will undoubtedly have positive impacts on the mental and physical health of babies as well as the family as a whole. Given the lasting burden of preterm birth for children and their families, this inspiring programme of work is shedding valuable light on transformative ways to improve neonatal intensive care.

Meet the researcher

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Dr Karel O'Brien obtained her Bachelor of Medicine, Bachelor of Surgery and Bachelor in the Art of Obstetrics at the National University of Ireland in 1983. She then completed her Master of Science in Clinical Epidemiology at the University of Toronto. Throughout her career, she has specialised in paediatric and neonatal care in clinical and academic settings, and since 2021, has been a Professor in the Department of Paediatrics, part of the Faculty of Medicine at the University of Toronto. She has been a Staff Neonatologist at Mount Sinai Hospital since 1992. Dr O'Brien has published extensively in her field and her work has received significant and prestigious funding. She has been featured regularly in the media highlighting the importance of family-centred care. Her work is changing how neonatal care is delivered by better supporting the development of positive parent-infant relationships to improve the short and long-term outcomes of infants and their families worldwide.

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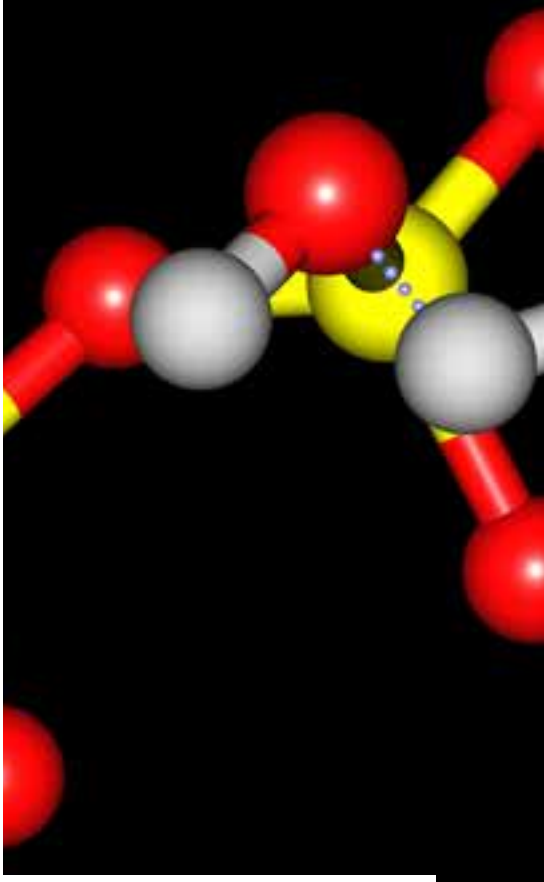
p38γ IT'S MORE THAN JUST A KINASE

Kinases take energy from adenosine triphosphate molecules to fuel other molecules in performing vital biological processes. **Dr Xu Hannah Zhang** at City of Hope, Los Angeles, has worked with colleagues to better understand the p38 family of kinases, and in particular, how the p38γ isoform plays a role in cancer. Her work has shown – for the first time – that p38γ is much more than just a kinase, and her recent studies point to new avenues in the search for cutaneous T-cell lymphoma therapeutics.



The Vital Work of Kinases

Vital biological processes such as cell growth and division (cell proliferation) and cell death (apoptosis) are fueled by chemical energy. In our bodies, adenosine triphosphate (ATP) carries chemical energy from the food we eat. Kinases then transfer this energy in the form of phosphates from the ATP molecules and add it to other molecules (such as sugars and other proteins) in a process known as phosphorylation.

In humans, the p38 mitogen-activated protein kinases (MAPK) family of kinases consists of four isoforms (also known as variants): p38α, p38β, p38γ and p38δ. Each isoform performs unique functions at different developmental stages in the lifespan, and while p38α and p38β are found throughout the body, p38γ and p38δ are only found in specific tissues.

p38γ: Links to Cancer

Our understanding of p38γ and p38δ is much less extensive than that of p38α and p38β. However, we do know that p38γ is associated with the spread of a diverse range of cancers (including colon, prostate, oesophagal, breast and liver cancers) and also cutaneous T-cell lymphoma, a rare form of cancer that begins in the white blood cells known as T cells and affects the skin, the body's largest organ.

Dr Xu Hannah Zhang at City of Hope and her colleagues, under the leadership of Dr Steven T Rosen, Provost and Chief Scientific Officer of the institute, recently explored the role of p38γ in cutaneous T-cell lymphoma – and uncovered some novel and important findings in the process.

To Bind or Not to Bind?

Binding sites (so-called 'pockets') are the parts of a protein that allow them to accommodate via affinity the smaller, incoming molecules. As p38γ shares its ATP-binding site with other kinases, Dr Zhang and her colleagues also studied a non-ATP-binding site to help them to identify any specific effects of p38γ. They were particularly interested in a hydrophobic (water-repelling) non-ATP site capable of attracting lipid-like small molecules, such as those required to target p38γ for the cure of the diseases such as cutaneous T-cell lymphoma.

In the field of bioinformatics, molecular docking is one of the most commonly used virtual screening methods supporting drug discovery and can be used to investigate interactions between small molecules and proteins. This is

the approach used by Dr Zhang and her colleagues to examine all 270,000 compounds currently available in the National Institute of Cancer Development Therapeutics Program library and assess the extent to which each would bind to the non-ATP site.

The 80 drugs identified as most effective in binding to the non-ATP site were investigated further using virtual screening to determine their potential toxicity to cutaneous T-cell lymphoma cells. Of these, Dr Zhang and her colleagues selected two small molecules: CSH71 and CSH18 (note that CSH18CN is a modified form of CSH18 to increase more specific binding). The researcers then confirmed the effects of both small molecules in the laboratory, using real samples.

As expected, both CSH71 and CSH18CN were toxic to cutaneous T-cell lymphoma cells. The effects of small molecule CSH71 were dose-dependent, but critically, at higher doses, CSH71 was found to bind to the ATP-binding site of p38γ and also the non-ATP site. This observation lead Dr Zhang and her colleagues to make the novel report that p38γ also functions as a non-kinase in T malignant cells, serving to drive cell proliferation. In contrast, normal healthy blood cells were spared because their p38γ is silent (not expressed).

Therapeutic and Other Implications

Dr Zhang and her colleagues propose that these new insights into how drugs can bind to the ATP-binding site and non-ATP binding site of p38γ will lead to treatment innovation in cutaneous T-cell lymphoma. Specifically, she proposes that targeting the non-ATP binding site will be a particularly fruitful avenue of exploration. It is also worth noting that her findings also validate the use of relatively new computational screening techniques in drug discovery with nuclear magnetic resonance Spectroscopy.

An Intriguing Idea

As a final aside, Dr Zhang notes that CSH71 treatment impacts olfactory receptors, which give rise to our sense of smell. The compound CSH18, as also studied by the researchers, impacts olfactory receptors but in a different collection to CSH71. This currently unpublished data from Dr Zhang lends support to the intriguing idea that each compound may trigger a unique 'fingerprint' for T cells to react to chemotaxis as part of its immune defence mechanism. She suggests that our current understanding of olfactory receptors may require revision, and further work to unpick how olfactory receptors interact with other cells and are regulated is now warranted.

Meet the researcher

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Dr Hannah Zhang completed her PhD in Biochemistry and Molecular Biology at Peking Union Medical College in China and then completed postdoctoral fellowships at Mount Sinai Hospital and Albert Einstein School of Medicine. She remained in New York to take up research appointments at Mount Sinai Hospital and Weill Cornell Medical College and was later appointed Assistant Research Professor at the prestigious City of Hope in Los Angeles. In 2022, Dr Zhang was appointed to her current position of Associate Research Professor. Her academic record of publications and funding is testimony to her extensive research experience and expertise in molecular biology, cell biology and immunology, and also her thorough knowledge of the molecular mechanisms of human disease.

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A NEW MODEL TO UNDERSTAND SHIGELLOSIS INFECTION

Shigella flexneri is a species of bacteria that causes approximately 270 million cases of Shigellosis (bacillary dysentery) each year, resulting in more than 200,000 deaths worldwide. **Professor Hervé Agaisse** and his team, based at the University of Virginia, USA, have proposed a new model of the disease. By adopting a multidisciplinary approach, they have recapitulated the symptoms caused by *Shigella flexneri* in the laboratory, enabling them to determine more precisely how these bacteria cause disease.

Bacillary Dysentery: Causes and Treatment

Bacillary dysentery is a severe gastrointestinal disease caused by the rod-shaped bacterium *Shigella flexneri*. It causes approximately 270 million cases of disease and over 200,000 deaths worldwide each year. Children aged under five and living in developing countries are sadly over-represented in these statistics.

The disease is characterised by profuse bloody diarrhoea and dramatic ulceration of the colon surface, the longest part of the large intestine. The bacteria are transmitted via the faecal–oral route – meaning it is transmitted from the stools of an infected person to the mouth of another, most often through contaminated water, hands or food.

Bacillary dysentery is extremely contagious. It replicates within human colon cells and spreads throughout the colon, leading to massive tissue destruction. The cellular and molecular mechanisms underlying the infection process in an individual are currently still not fully understood. However, the increasing and alarming presence of *Shigella flexneri* strains that are resistant to multiple antibiotics has generated urgency for a better understanding of how this particular pathogen causes disease in humans.

During infection, *Shigella flexneri* invades the cells which line the surface of the colon. The bacteria then hijack the host cell actin cytoskeleton, which is a microscopic network that determines cell shape and motility (movement), to move within cytosol, a fluid found inside living cells. The bacteria spread from cell to cell through the formation of 'fingerlike' membrane protrusions which project into adjacent cells.

Upon spreading from one cell to another via these protrusions, the bacteria are entrapped in cell membrane compartments termed 'double membrane vacuoles'. These are composed of an inner membrane, originating from the primary infected cell, and an outer membrane deriving from the adjacent cell. By escaping the double membrane vacuoles, *Shigella flexneri* gains access to the adjacent cells and thus achieves its spread. Initial invasion of epithelial (surface) cells

such as those in the colon and then the cell-to-cell spread are both critical determinants of disease development.

Compared to the mechanisms supporting actin-based motility of *Shigella flexneri*, the mechanisms underlying cell-to-cell spread have received less attention. Professor Hervé Agaisse and his team, based at the University of Virginia in the USA, set out to understand this process more fully through the development of a novel animal model.

The model developed by Professor Agaisse is the first to recapitulate symptoms of human disease caused by *Shigella flexneri*, representing a

significant advancement in the field. Their recent research has looked at the Shigella 'effectors' – the secreted proteins produced by the pathogenic bacteria that manipulate the host cell during infection. Using a multidisciplinary approach, Professor Agaisse's laboratory has investigated how both the bacterial and those host factors that are hijacked are required for this infection process. This vital work has provided us with a much better understanding of how the pathogen operates.

Development of a Novel Animal Model

The use of in vitro tissue culture systems where cells or fragments of tissue from an animal are grown in the laboratory has been instrumental in defining the molecular mechanisms supporting the invasion of *Shigella flexneri* into cells.

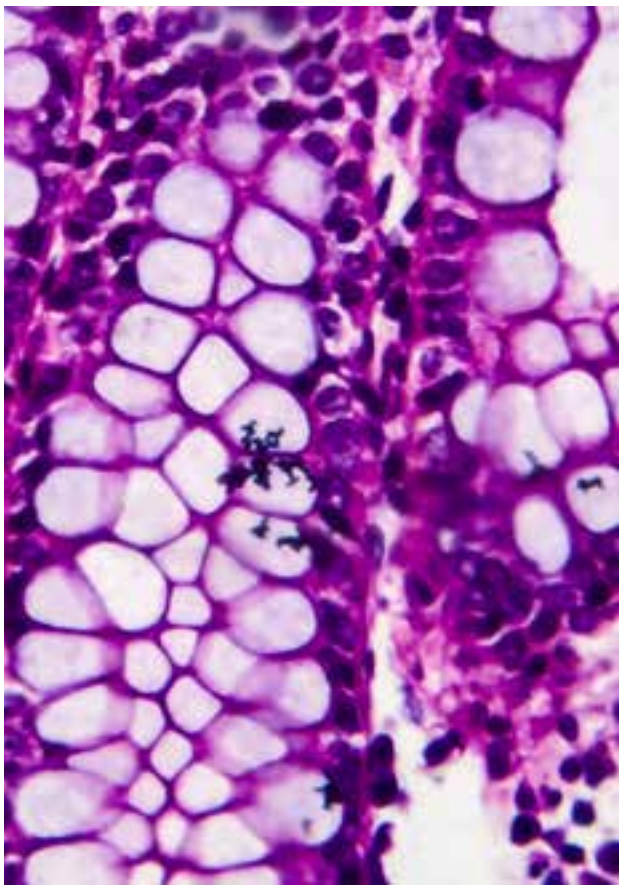
This research led to the discovery that *Shigella flexneri* invasion relies on the presence of a particular 'invasion plasmid', a small circular DNA strand encoding the bacterial type-3 secretion system. The type-3 secretion is a microscopic needle that *Shigella flexneri* uses to 'inject' its proteins into host cells.

Bacterial effector proteins, which are delivered into targeted host cells by the secretion system manipulate various cellular processes, including the actin cytoskeleton, leading to the uptake of the bacteria into compartments made of host cell membrane termed primary vacuoles. Escape from primary vacuoles allows the pathogen access to the host cell cytosol.

Cytosolic bacteria express a protein known as 'IcsA' which is involved in the recruitment of the host cell actin assembly machinery at the bacterial pole. This process of actin polymerisation propels the pathogen throughout the cytosol of infected cells, which ultimately enables cell-to-cell spread into adjacent cells.

There is a significant gap in knowledge as to how the biology of *Shigella flexneri* infection relates to the development of the disease in its human hosts. This is partly due to the lack of small-animal models of bacillary dysentery. *Shigella flexneri* is a human-specific pathogen and the only known animals that display the symptoms observed in infected humans are other non-human primates. Various small-animal models have been developed and used in the past, but unfortunately, most of these models are not relevant to the site of *Shigella flexneri* infection in humans – the colon.

Furthermore, none of these models can recapitulate bloody diarrhoea, the hallmark of human Shigellosis. Professor Agaisse and his team, therefore, developed an infant rabbit model of bacillary dysentery that recapitulates all the symptoms of human shigellosis. They used it to explore the role of bacterial factors which were critical to intracellular infection in tissue culture systems, including the type-3 secretion system and the dissemination factor IcsA.



Remarkably, despite the early signs of immune cell infiltration and vascular lesions, the animals infected with bacteria lacking IcsA did not experience any signs of bloody diarrhoea or related weight loss. This infant rabbit model highlights the critical role that cell-to-cell spread plays in causing bacillary dysentery. Targeting cellular mechanisms that support *Shigella flexneri* spread from cell to cell may therefore represent a promising medical prevention. As such, the infant rabbit model provides an unprecedented framework for understanding how the biology of *Shigella flexneri* infection relates to the development of disease in humans.

The Art of Manipulation

As the researchers demonstrated using the infant rabbit model, the ability of *Shigella flexneri* to spread from the initially infected colon cell to neighbouring cells is essential for disease symptoms to develop. Professor Agaisse and his team investigated the cellular and molecular mechanisms of how Shigella manipulates the host cell during an infection, and thus allows cell-to-cell spread.

Shigella flexneri spreads within the colon by displaying actin-based motility in the cytosol of epithelial cells. Motile bacteria form membrane protrusions that project into adjacent cells and resolve into double-membrane vacuoles from which the bacteria escape, thereby achieving cell-to-cell spread. Once it's entered a cell, *Shigella flexneri* is targeted by a type of autophagy, a host cell defence mechanism used to fight intracellular pathogens.

It was proposed that an effector protein called 'IcsB' produced by the bacteria is responsible for counteracting the recruitment of a type of autophagy machinery to bacteria located in the cytosol. However, a more recent study proposed that this autophagy machinery was instead recruited to bacteria located in double membrane vacuoles formed during cell-to-cell spread. To clarify the role that autophagy plays in managing *Shigella flexneri* infection, Professor Agaisse and Dr Erin Weddle looked at bacterial spread using a special type of microscopy and determined the spatial and temporal recruitment of autophagy machinery in response to the presence of *Shigella flexneri* bacteria.

Their results demonstrated without doubt that IcsB produced by the bacteria is required for double membrane vacuole escape during cell-to-cell spread, regardless of autophagy machinery recruitment by the host cell, providing a direct challenge to the previously proposed theory that autophagy combats *Shigella flexneri* spread.

Professor Agaisse and Dr Weddle also characterised another effector protein called 'IpgB1'. This is produced by *Shigella flexneri* and allows the bacteria to spread throughout the human colon. The researchers discovered that IpgB1 manipulates host cell signalling proteins to escape the double membrane vacuoles and spread throughout the colon. In another recent study, Professor Agaisse and Dr Volkan Köseoğlu showed that *Shigella flexneri* employs the activity of another effector protein called 'IpgD' to manipulate a type of lipid molecule that is found in the protrusion membrane. This affects the formation of actin networks underneath the protrusion membrane, which would otherwise prevent the stepwise progression of protrusions into double-membrane vacuoles during cell-to-cell spread.

Using their rabbit model, the researchers also demonstrated that the bacterial effectors IpgB1 and IpgD are required for efficient dissemination in the colon of infant rabbits and contribute to the severity of disease. Together, these studies converge to illustrate how Shigella effectors can manipulate the host cell during infection and allow for cell-to-cell spread.

Implications for Therapeutic Development

The team's work has provided a unique small-animal model that will facilitate further research and the development of therapeutic interventions against *Shigella flexneri* infections. The lack of an effective vaccine and the presence of Shigella strains that are resistant to multiple antibiotics has generated urgency for an increased understanding of how this particular pathogen operates. Professor Agaisse's work provides insight into the mechanisms by which *Shigella flexneri* causes disease and suggests several novel therapeutic targets. Targeting the bacterial and cellular mechanisms that support *Shigella flexneri* spread from cell to cell may represent promising a method for reducing cases of bacillary dysentery in humans.

Meet the researcher

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Professor Hervé Agaisse obtained his PhD at the Pasteur Institute in Paris and then completed postdoctoral training at Harvard Medical School, USA, between 1998 and 2004. In 2005, he set up a laboratory at Yale University, working to systematically identify host genes supporting the dissemination of intracellular pathogens. In 2015, Professor Agaisse joined the University of Virginia, where his current research focuses on the molecular and cellular mechanisms involved in *Shigella flexneri* infection in tissue culture systems and newly developed small-animal models of bacillary dysentery. The Agaisse Laboratory is committed to the development of therapeutic interventions to overcome the challenges of bacterial disease. To this end, Professor Agaisse and his team utilise a multi-disciplinary approach integrating molecular and cellular microbiology, bacterial and host cell genomics, bioinformatics, and unique animal models of pathogenesis..

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FUNDING

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UNRAVELLING HOW COVID-19 MATHEMATICS IMPACT BEHAVIOUR CHANGE

Mathematical models for predicting the spread of COVID-19 directly influenced public health measures around the world, significantly impacting everyone's day-to-day activities. At Kingston University, **Dr Cristina Oliva** and **Professor Giampiero Favato** are leading the way in COVID-19 research, looking at how complex statistical data is communicated to the general public. Their valuable work is helping drive changes in behaviour that could reduce the spread of COVID-19.

Flattening the Curve?

The COVID-19 pandemic changed how we live our lives – from our working habits to wearing masks in public to our contact with others, even close family members. Mathematical models were used to predict how the infection could spread and the public was bombarded with statistics about 'flattening the curve'. Measures including social distancing and lockdowns were put in place by governments across the world. Yet despite the severity of the situation, many people did not adhere to these measures.

During the pandemic, Dr Oliva and Professor Favato joined their research to better understand the spread of COVID-19, gathering vital data to help the fight against this infection. More specifically, they explored how the way in which mathematical information is explained to the public leads to changes in behaviour.

Simple, visual data were most commonly used to disseminate mathematical information about the spread of COVID-19 to the public. Line charts were used throughout the media to help communicate the importance of public health measures. It was proposed that flattening the curve was necessary to reduce the number of COVID-19 cases and stop hospitals from becoming overwhelmed. However, the researchers argue these line charts failed to effectively communicate to individuals the high risk of infection and thus, the importance of avoiding close contact with others was simply not heard by many.

The public health measures relied on people changing their behaviours and maintaining these changes over time. However, when asking such dramatic changes in how people behave, the researchers suggest that many factors need to be considered. In particular, they argue that how such messages are framed will play an important role.

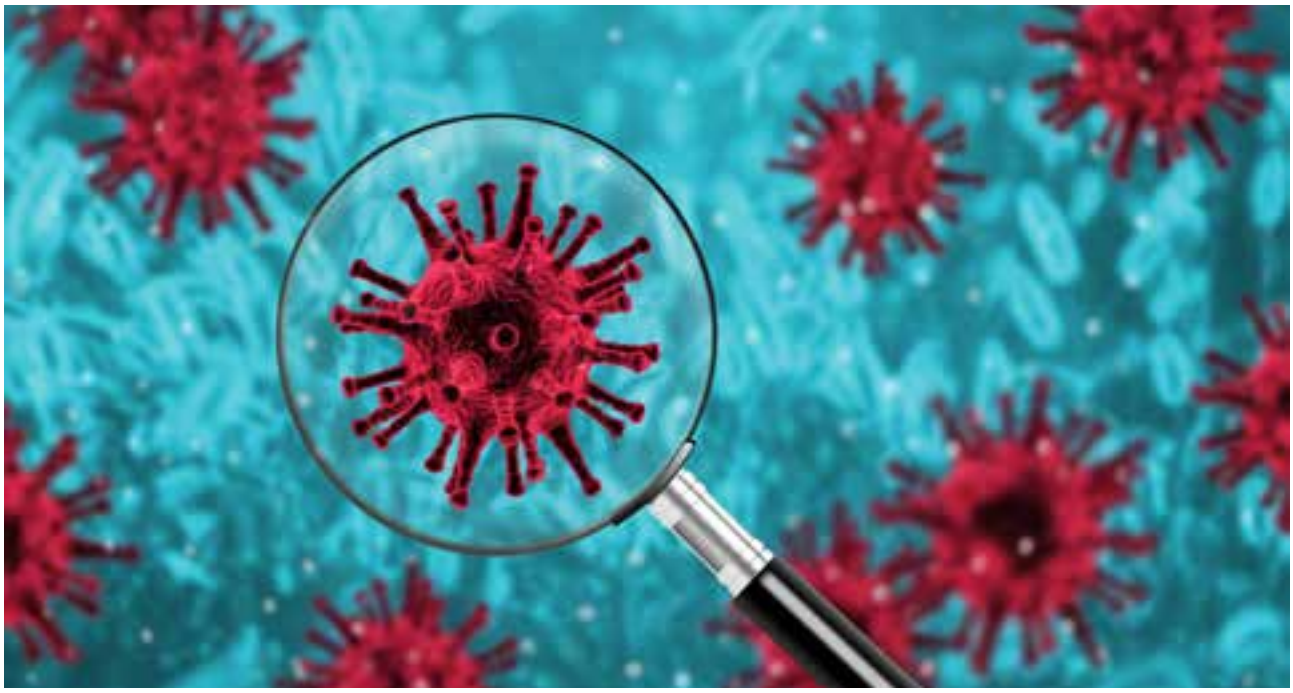
Using Behavioural Sciences to Tackle Health Problems

At the start of their research, the researchers turned to the behavioural sciences to explore how and why people make decisions about their actions, with one of the underpinning constructs

being the Health Belief Model. This model, adapted from behavioural science theories to health problems, is one of the most widely recognised models of health-related behaviour.

In essence, the Health Belief Model suggests that a person's belief in the personal threat of a disease (COVID-19 in this case) coupled with their belief in the effectiveness of the required behaviour (for example, wearing a mask and social distancing), will predict how likely they are to undertake that behaviour.

The researchers explored how this model might apply to the reasoning behind people's choices during the COVID-19 pandemic. They focused on four areas of perception (susceptibility, severity, benefits and barriers) that people consider and evaluate when making



health decisions, and linked this to the likelihood of them adopting a particular health behaviour relating to COVID-19 (such as wearing a mask).

The review of existing research led Dr Cristina Oliva to identify three key cognitive biases (which are subconscious errors in thinking that can affect the accuracy and rationality of decisions) directly relevant to health beliefs: identifiable victim effect, present bias and omission bias.

The researchers then applied these cognitive biases to the Health Belief Model. For example, they proposed that people responding more strongly to threats against themselves or people they care about (the identifiable victim effect) related to the concepts of perceived susceptibility and severity in the Health Belief Model.

For the researchers, this was an important opportunity to 'manage the meaning' of the COVID-19 data. The team then looked into paradoxically turning these cognitive biases into 'cues to action' – in other words, how to positively modify personal beliefs and, as a consequence, health behaviours.

Keeping the Elderly Safe

The relevant COVID-19 research was carried out in Italy. After the initial outbreak in China, Italy was one of the first countries to be hit by COVID-19, with over 25.5 million confirmed cases in the last three years, according to the World Health Organisation. The Italian Government set out new and urgent legally binding measures to contain the spread, which imposed restrictions on individuals to help mitigate the risk of exposure to the virus.

The researchers and their colleagues published the very first model to identify the elderly living in RSA as a primary target for COVID-19 mortality (Residenza Sanitaria Assistenziale is a type of nursing home, particularly for those requiring a higher level of care). The findings of this breakthrough study indicated that a significant reduction of social contact in metropolitan areas, along with the timely isolation of elderly and diabetic residents, could greatly impact the death toll in subsequent COVID-19 waves.

The researchers then coupled COVID-19 death statistics in different regions of Italy with determinants of health (factors that relate to how healthy people are) from a review of the current literature. They used mathematical methods to predict variations in mortality observed when the COVID-19 infection first swept through Italy.

As such, Dr Oliva and Professor Favato 'drew a face' on the maths. Using the Health Belief Model, they suggested that the 'flatten the curve' narrative does not convey perceived susceptibility and severity adequately because of the identifiable victim effect cognitive bias. Knowing the cumulative number of infections and deaths may fail to encourage people to change their behaviours – but knowing that an elderly relative is at high risk could help individuals make better choices.

Identifying Risky Activities

Dr Oliva and Professor Favato continued their ground-breaking COVID-19 research with a large-scale investigation into the risk of exposure to COVID-19 with day-to-day activities. They were the first researchers to use Google Maps data about visitation duration to estimate the exposure risk of different activities.

The researchers knew that COVID-19 spreads through close contact but when social restrictions were eased, new questions arose. Which activities posed a greater risk of exposure, and for

particular activities could the risk be reduced somehow? They explored the Health Belief Model concepts of perceived benefits and 'present bias' in thinking, relating them to how people chose activities during the pandemic. They suggested that people will tend to give priority to immediate gratification, such as eating out in restaurants, over larger future benefits like reducing the risk of being exposed to COVID-19.

Since there was no current information available to help people make informed decisions about their activities, the aim of this study was to make the risk versus benefits 'trade-off' more visible by estimating the exposure risk by activity and location in urban areas.

Professor Favato and Dr Oliva used new features on Google Maps to gather data about the average visit duration for over 500 activities in Genoa, such as grocery shopping, and bank and post office visits. They discovered there were significant variations in the risk of exposure amongst different activities as well as different locations for the same type of visit.

The authors presented their findings using an intuitive numeric form to define the exposure risk in order to help public health policymakers effectively communicate the urgency of containment measures. They believe that the most significant impact of this research was to make individuals aware of the absolute and relative risk of exposure to COVID-19. This knowledge then empowered them to make active choices about their behaviour.

The Second Wave and Beyond

Dr Oliva and Professor Favato teamed up again to investigate the Delta variant during the second wave of the pandemic. This COVID-19 variant was more easily spread with close contact durations going from minutes to only seconds for infection to occur.

The risk of exposure was vastly increased and so, the perceived barriers that the team identified as preventing changes in behaviour needed to be addressed. The researchers pointed to the role of omission biases supporting the erroneous thinking of 'why bother?' with behaviours such as mask-wearing and social distancing. This is consistent with the observation that people tend to prefer harm occurring due to failing to take action rather the taking preventative action that might not work at all.

This most recent study was the first of its kind to use game theory – a mathematical model of how interactions can occur – to model the most effective response to COVID-19 variants. The researchers utilised Google Maps data again, in a similar way to their previous study to track visit duration time in different activities, and found that the absolute risk of exposure to the Delta variant increased by sixfold compared to the ancestral form (original COVID-19 virus). In relative terms, however, the differences in exposure risk for various activities did not significantly differ from that of the ancestral form of COVID-19.

While the Delta variant represented an evolution of COVID-19, the researchers concluded that the best response was to commit to the original plan and continue to work on addressing psychological barriers that could influence the effectiveness of population-wide vaccination and social distancing. As the threat of the COVID pandemic still looms over us, Dr Oliva and Professor Favato's work may be key to mitigating its impacts in time to come.

Meet the researchers

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Cristina Oliva is a core member of the Institute of Leadership and Management in Health at Kingston University. She has been a practising oncologist for over 12 years at several national cancer institutes, treating a wide variety of oncology diseases. During her experience in clinical research, she has contributed to the development of new therapeutic approaches in gynaecological malignancies. Her experience ranges from early to late-stage clinical studies and as the lead of international teams, she has successfully brought several new compounds to their regulatory approval, across a variety of indications and mechanisms of action. Dr Cristina Oliva graduated as MD at the University of Genoa in 1988 where she also obtained her oncology board certification in 1991. She has authored more than 100 publications to date and is a member of the American Society of Clinical Oncology and the European Society of Medical Oncology, and holds registration with the General Medical Council in the UK.

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Professor Giampiero Favato is the Director of the Institute of Leadership and Management in Health at Kingston University. He is also a Fellow of the Royal Society of Public Health, the Royal Society of Medicine, and the European Cancer Organisation. Professor Favato's research has played an important role in public health policy, including Public Health England's gender-neutral human papillomavirus vaccination programme. His most recent work focuses on reducing the mortality risk of COVID-19 infection for the frail, elderly population. Before his academic career, Professor Favato undertook strategic and financial responsibilities in the life sciences industry. He received an MBA from the University of Chicago Booth School of Business in 1999, and a DBA from the Henley Management School, part of the University of Reading, in 2003.

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PRECISION MEDICINE – AN IMPORTANT APPROACH IN ADVANCING CANCER TREATMENT

In precision medicine, disease prevention and treatments are specifically tailored to each individual patient, taking into account their genetics and physical function. For individuals with cancer, clinicians can carry out genomic testing to identify key markers that can be targeted for treatment. While advances in medicine mean that precision medicine has become more accessible, the efficacy of the approach in cancer remains unclear. **Dr Xin-Hua Zhu** at the Zucker School of Medicine at Hofstra/Northwell is committed to providing definitive answers as to how best we can use precision medicine in cancer treatment.

Cancer Treatment – One Size Does Not Fit All

There are more than 200 types of cancer that can be found in different organs and originate from different cell types. Despite this complexity and variability, cancer treatment plans tend to take a 'one size fits all' approach, with everyone with the same cancer type receiving a combination of the standard four treatments: surgery, radiation therapy, chemotherapy and immunotherapy.

Through years of accumulated knowledge in cancer research, we now know that cancers are highly heterogeneous. This means that any particular cancer will most likely not be exactly the same as that of someone else who has cancer, even in the same organ of their body. Thus, not all patients with the same cancer type will respond the same way to treatments, and any particular class of cancer drug can be ineffective in an estimated 75% of patients. Non-responders to cancer treatment often suffer from unnecessary adverse effects as a result of treatment and of course, inherent to this is also a delay in progression to an effective treatment.

Precision medicine aims to deliver a more targeted treatment. A sample taken from a patient's tumour will be sent off to have the genome 'read' in a process known as genomic sequencing. Then, identification of the genomic changes (aberrations) of tumour cells allows researchers to identify potentially actionable information to help guide treatment decisions. With breakthroughs in our understanding of which genomic changes can drive tumour growth, we are now able to identify 'driver mutations' by using the widely available technique known as next-generation sequencing. Understanding this background for each patient facilitates a more targeted approach in which aberrations in the genomic profile of a tumour can be targeted to reduce aspects such as growth rate and also help induce tumour cell death.

Although genomic testing allows for an in-depth examination of the genomic profile of a tumour and its aberrations, factors such as physical function, the type of cancer, how big it is and whether it has spread to other locations in the body also play a part in determining treatment options. This multifactorial tailoring in treatments means, in theory, that there will be a reduction in the number of patients going through treatments that will not be effective for them as a result of their cancer type associated with the genetic background. Optimising tumour response, taking into account the therapy-induced toxicities for each specific patient and combining optimised tumour response with the preservation of organ function

will help to maintain the quality of life for patients undergoing treatment. However, before this is possible across the board for all cancer patients, further work is needed in identifying biomarkers and matching these with effective treatments.

Moving Precision Medicine Forwards

Many factors have led to precision medicine becoming an increasingly popular and accessible option in clinical practice. These include an increased understanding of driver mutations, the accessibility of genomic testing for patients, and the development of more targeted treatment options. Over the past decade, several key precision medicine approaches have emerged with targets including neurotrophic receptor tyrosine kinase (NTRK) gene fusions, microsatellite instability-high (MSI-H) or deficient mismatch repair (dMMR) and tumour mutation burden-high (TMB-H) used to select therapies regardless of the tumour origin.

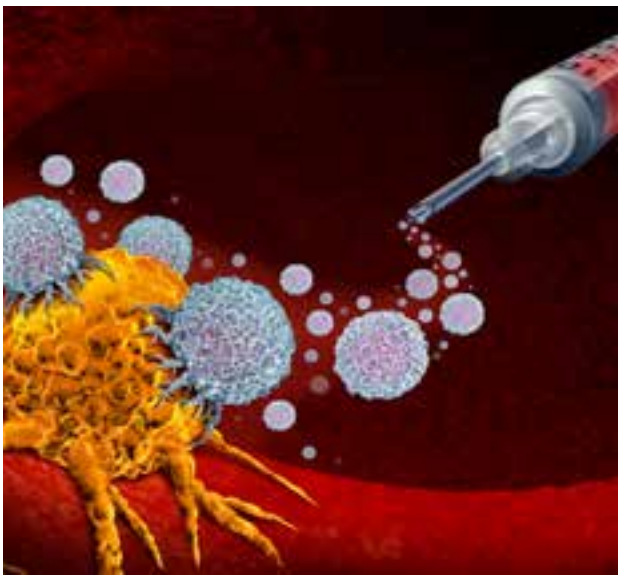
The discovery of these biomarkers as therapeutic targets has resulted in the development of treatments such as NTRK blockers (e.g., larotrectinib and entrectinib), microsatellite instability, and MSI-H or dMMR or TMB-H with pembrolizumab (programmed death 1 (PD-1) blocker). These are all USA Food and Drug Administration-approved drugs for patients who test positive for these biomarkers.

The biomarkers identified as having targetable treatments are epidermal growth factor receptor, anaplastic lymphoma kinase fusion, B type Raf kinase mutation, PD-1, KRAS G12C mutation, ROS1 rearrangement, RET rearrangement and MET mutation in non-small cell lung cancer, HER2 amplification, PIK3CA mutation and ESR1 mutation for breast cancer.

Dr Xin-Hua Zhu at the Zucker School of Medicine at Hofstra/Northwell is pushing forward the field of precision medicine by identifying biomarkers and exploring the associated treatment options in mixed cancer types, bladder, and renal cancers. His approach to highlighting potential biomarkers for targeted treatment differs from other research in that he combines messenger ribonucleic acid (mRNA) and microRNA (miRNA) expression results to gain an overall picture of gene expression. Importantly, mRNA represents the differential expression of genes and miRNA can act as an oncogene or a tumour suppressor gene, with the capability to promote or suppress cancer development.

Examining the expression of both mRNA and miRNA allows for the detection of how highly they are expressed in the tumour cells, meaning that highly expressed or downregulated 'driver' genes can be identified as potential therapeutic targets.

Dr Zhu's initial work involved a retrospective study of 652 patients, across 10 different cancer types, 135 of whom received targeted therapy as a result of biomarker testing. Here, the most common alterations in the tumours were KRAS, PI3K and BRAF followed by PD-1/PD-L1. They found that 23.5% of the patients who received targeted therapy had a partial response rate, 17.6% resulted in stable disease and the disease control rate was 41.1%. These promising results suggested a clear potential for precision medicine in real-world community oncology practice, and warranting further large and prospective studies in patients with targetable biomarkers regardless of tumour origin.



Dr Zhu then completed studies in muscle invasive bladder cancer and in doing so, contributed significantly to the growing school of thought proposing a vital role of mitochondrial response genes, DNA replication genes and DNA damage genes in differentiating response versus non-response to neoadjuvant chemotherapy (NAC). Previous studies had shown that p53-like tumours are mostly resistant to NAC – a finding that was later backed up by Dr Zhu's study in 2022, in which 90% of patients who did not respond to NAC were also found to have p53-like tumours. This is consistent with the known profile of the p53 signalling pathway which monitors DNA replication and cell division, and responds to intrinsic and extrinsic stress signals. This also suggested the potential for this pathway as a therapeutic target.

Further research by Dr Zhu has focussed on investigating potential genes involved in metastasis in stage I and II patients – in particular, clear cell renal cell carcinomas (ccRCC). Research into metastatic cancer therapies is particularly important in precision medicine, as once a tumour has metastasised (appeared elsewhere in the body away from the primary tumour site), treatment becomes much more difficult. Dr Zhu's work identifying the molecular signatures of more aggressive tumours in clinically low-risk ccRCC patients should allow for gaining a better understanding of the future metastatic potential of tumours and thus, shape the proposed treatment strategy.

Problems with Precision Medicine

Although this is an exciting field of research, precision medicine does not come without some frustrations and dilemmas. Cancer, by nature, evolves over time and even after treatment. As such, implementing a full precision medicine treatment plan after diagnosis could require multiple rounds of genomic testing between each treatment type – an expensive and time-consuming process.

Alongside this, our knowledge of targetable biomarkers and matched treatments, whilst much improved compared to 10 years ago, is still not at a point where we fully understand the possible impacts of this approach. Even carrying out clinical trials in this area can be difficult, as clinical trials are often carried out in patients whose disease has progressed after the available standard of care has been provided. The condition of these patients can deteriorate rapidly, leading them to leave trials early or before testing results have been returned and the patient moved to hospice care. In addition to this, clinical trials in this area often involve only a small number of patients, and therefore, are not always fully representative of the true patient population.

When it comes to implementing precision medicine clinically, multiple targetable drugs are often available for patients based on their genetic background. This can result in a lack of clarity around the selection of the 'best option' for patients going forwards – a factor that is exacerbated by many physicians having low confidence in their knowledge of gene functions. However, further research in this area to improve our knowledge will likely lead to improved identification of treatments for patients and wider recognition of the possible options that clinicians may offer.

A Brighter Future Lies Ahead

Despite these difficulties, an increase in the knowledge and resources that precision medicine can offer has the huge potential to increase the effectiveness of cancer treatment plans. Already, improved patient response rates and progression-free survival have been seen in early-stage clinical trials that have used biomarkers to select patients. Nonetheless, there is still a long way to go before precision medicine becomes fully embraced, and a coordinated effort between researchers, pharmaceutical companies, regulators, clinicians and patients is needed to drive this emerging but important field forward.

Meet the researcher

Dr Xin-Hua Zhu
Donald and Barbara Zucker School of Medicine at Hofstra/Northwell
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Dr Xin-Hua Zhu is a physician-scientist holding both an MD (Soochow University Medical College, China) and PhD (Shanghai Jiao Tong University School of Medicine, China). He completed his postdoctoral training at Memorial Sloan Kettering Cancer Center and is currently an Associate Professor at Donald and BarbaraZucker School of Medicine at Hofstra/Northwell. Dr Zhu is board-certified in internal medicine, haematology and medical oncology. He completed his residency in Internal Medicine at Mount Sinai Medical Center and also completed a Hematology and Medical Oncology Fellowship at New York University Langone Medical Center. His work is dedicated to the treatment of genitourinary and cancers and in particular, identifying biomarkers for renal, bladder, pancreatic and prostate cancer. Dr Zhu is an active member of the American Association for Cancer Research, the American Society of Clinical Oncology, and the American Society of Hematology and has received some funding to support his vital research.

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FUNDING

Northwell Health Cancer Institute
National Institutes of Health

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Northwell Health Cancer Institute

A QUEST FOR ZERO HEART ATTACKS

Heart attacks and cardiovascular disease are broadly considered to be the result of unhealthy habits and underlying health issues. However, pioneering research led by interventional cardiologist **Professor Gemma Figtree** from the University of Sydney reveals that approximately one-quarter of first-time heart attack patients do not have any known modifiable risk factors. These patients develop 'silent' coronary artery disease, without any warning signs. Professor Figtree and her international team at CAD Frontiers are pioneering a new approach to heart attack prevention that goes beyond traditional risk factors and symptoms.

The Leading Cause of Mortality

In the average lifetime, our hearts beat three billion times, nourishing themselves through the coronary arteries. It is widely understood that smoking, high blood pressure, diabetes, and high cholesterol levels can damage these arteries, leading to the formation of fatty deposits. If this obstruction becomes complete – most often involving rupture of the plaque and triggering a blood clot – energy and oxygen supply stop altogether to a section of the heart, causing a heart attack. Unless treated promptly, this can be life-threatening.

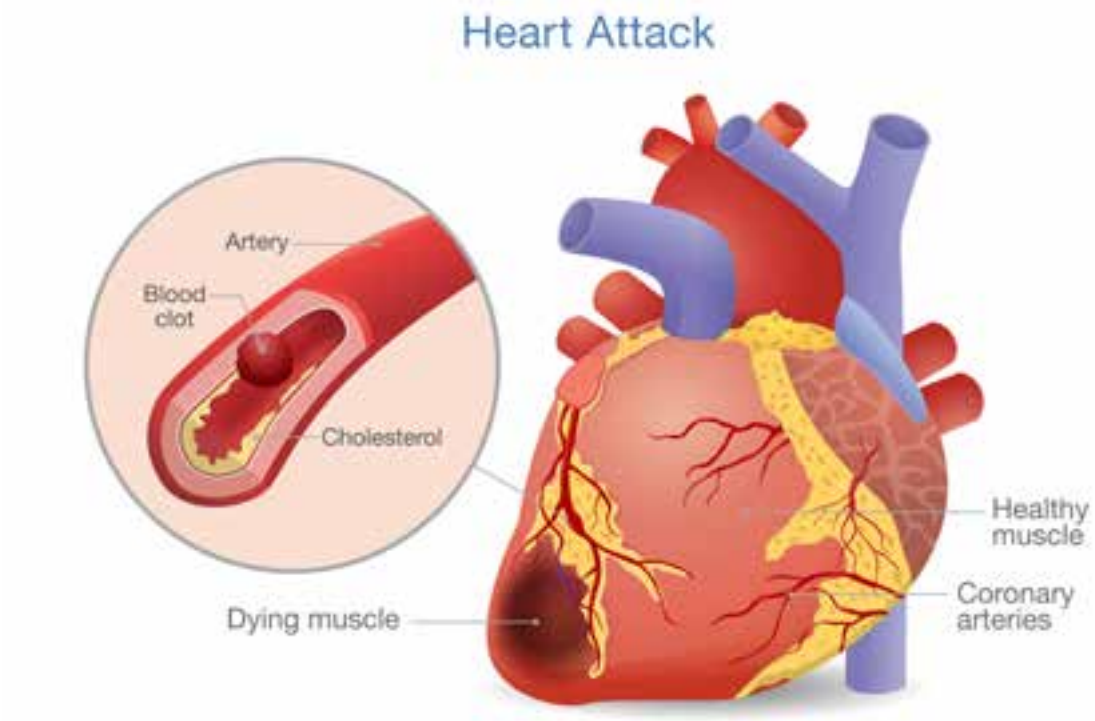
In Australia, a country with a population of 27.5 million people, a heart attack occurs every nine minutes. Tragically, some individuals succumb instantly, even before an ambulance can be called. The lives of those who survive are often blighted by long-term consequences.

Physicians worldwide strive to identify individuals at risk of coronary artery narrowing and prevent the condition's progression before it leads to a heart attack. Traditionally, clinicians have relied on modifiable risk factors such as cholesterol, blood pressure, smoking and diabetes to guide preventive strategies. However, an increasing number of first-time heart attack patients have no risk factor 'alarms' and silently develop coronary artery disease (CAD) over time. It is not uncommon for patients to present with extensive atherosclerosis and a life-threatening heart attack without any evident risk factors or prior symptoms, leaving them questioning, 'Why me?'.

Recent data highlight the importance of unravelling new markers for CAD. In 2015, approximately 27% of patients with identified plaque rupture and life-threatening ST-elevation myocardial infarction (STEMI) had none of the **S**tandard **M**odifiable cardiovascular **R**isk **F**actors (SMuRFs). This proportion has steadily risen from 14% over the past decade.

Professor Gemma Figtree of the University of Sydney and her team have spearheaded a global effort to understand the mechanisms, outcomes, and management of this SMuRFless patient group. Collaborating with the SWEDEHEART registry, which

includes 62,048 STEMI patients, in 2021 they reported in The Lancet on the experience of people with SMuRFs compared to those without. Worryingly, these SMuRFless individuals fared poorly after initial hospital treatment. A greater number of them died within 30 days of the initial heart attack compared to patients with traditional risk factors, a trend that disproportionately affected women. In patients predisposed to heart attacks due to smoking, diabetes, high blood pressure or high cholesterol levels, addressing the underlying problem will drastically reduce the chances of first time or recurrent heart attacks. But what can be done to prevent a heart attack in someone who doesn't present with any of these modifiable factors?



Invisible Heart Attack Patients in Trials and Guidelines

In their study of the medical literature, Professor Figtree and her team discovered a striking omission. Out of 256 clinical trials reporting on heart attack treatment, none of them reported the number of SMuRFless patients included in the study or the outcomes of their treatment.

Various national and international guidelines provide detailed steps for physicians to follow in the preventive management of heart attack patients with modifiable risk factors. However, the researchers found no specific guidance on managing heart attack patients who lack these risk factors. Professor Figtree refers to these SMuRFless patients as 'invisible' in current management and research. Consequently, an estimated 1.34 million people worldwide die each year as a result of SMuRFless heart attacks.

A Call for Action

In response to the challenges faced by these invisible patients, Professor Figtree has led an international consortium of physicians, scientists and industry experts under the banner of CAD Frontiers, with key founding partners, the University of Sydney, Snow Medical Research Foundation, LaTrobe University, Baker Heart and Diabetes Institute, and Monash University (CADFrontiers.com.au). While the initiative is Australian-based, the team has an established international presence, with leading experts from Europe, Asia, and America working towards the vision of 'a world without heart attacks'. The team collaborates with patient groups, healthcare partners and experts in the commercialisation of emerging medical technologies to accelerate the translation of urgently needed solutions.

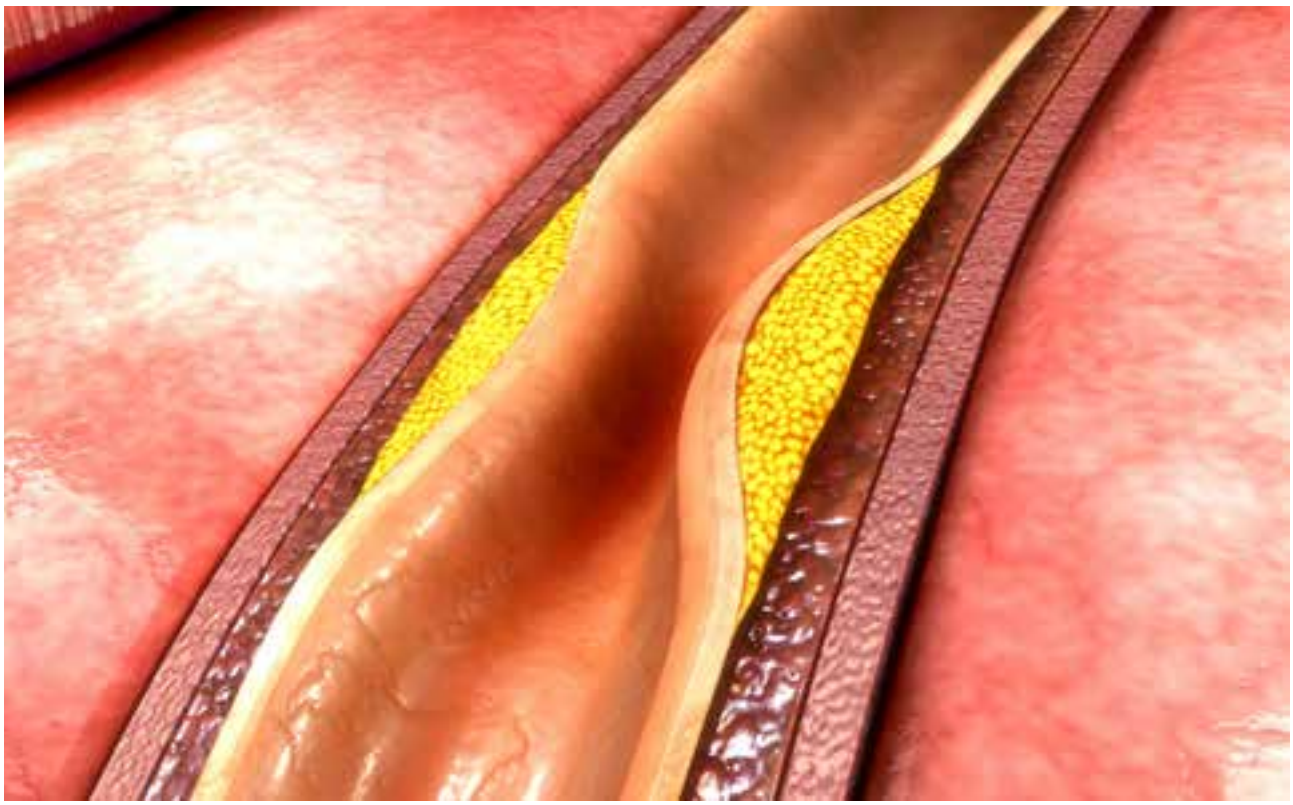
Confronting a Complex Challenge

The first challenge facing the consortium is understanding why these patients experience heart attacks in the absence of traditional risk factors. While extensive research has explored the mechanisms behind CAD in response to smoking, diabetes, high blood pressure and high cholesterol, medical science has limited insight into why some individuals develop this condition in the absence of recognised risk factors. As this patient group represents a subset of heart attack sufferers, their unique data must be separated from the broader patient population. Professor Figtree emphasises the need to 'split' rather than 'lump together' this group, suggesting that modern approaches utilising artificial intelligence may hold the key.

Unlocking the Potential of 'Omics'

The concept of 'omics' may be unfamiliar to many non-scientists. In brief, this technology enables the identification of all genetic information (genomics), proteins (proteomics), fats (lipidomics) or produced chemicals (metabolomics) within an individual. Recent technological advancements have made rapid and comprehensive analysis of these biological molecules possible.

If specific 'omic signatures' for particular medical conditions can be identified, these signatures can be used to predict disease. SMuRFless CAD – conservatively estimated to cause 1.34 million deaths in 2019 alone – ranks among the top five conditions driving global mortality. Even if a marker could accurately identify 50% of otherwise overlooked patients with silent CAD, it has the potential to dramatically reduce heart attacks.



Professor Figtree and her team continue to make advances in identifying previously unrecognised molecules in the blood that can serve as powerful biomarkers for assessing the burden and activity of silent CAD. The overarching aim of CAD Frontiers is to develop a series of blood-based biomarkers for CAD, revolutionising heart attack prevention. Simultaneously, the team aims to explore the identified CAD biomarkers and whether they point to potential novel therapeutic targets.

Looking Ahead to Future Therapies

Most current drugs used for the clinical management of CAD and heart attack prevention target modifiable risk factors, such as statins for cholesterol and angiotensin-converting enzyme inhibitors for blood pressure. However, our understanding of the factors driving individual susceptibility and resilience to CAD remains limited.

CAD Frontiers' drug development programme adopts a novel approach, leveraging relevant expertise, resources, and partnerships to advance knowledge regarding causal factors of CAD, identify diagnostic targets, and develop new treatments in a bench-to-bedside approach. This comprehensive translational pathway ensures the discovery and translation of new therapeutic pathways and drugs that benefit all individuals at risk of heart attacks and sudden death.

The development of new drugs faces significant obstacles, particularly the cost of clinical trials, which can amount to billions of dollars. CAD Frontiers believes that costs can be reduced by up to 20-fold through targeted testing on smaller, better-characterised patient populations. Changes in trial design and reporting can also expedite the process of bringing new drugs to market.

Professor Figtree emphasises the global inequality in healthcare provision, with approximately 75% of all heart disease patients residing in low- and middle-income countries. Access to new drugs and treatments may be challenging or impossible for individuals in these regions. CAD Frontiers aims to improve healthcare in disadvantaged communities, including ensuring more equitable access to therapeutics in poorer countries.

Making Heart Attacks a Thing of the Past

CAD Frontiers presents a new vision and strategy to address the leading cause of premature death worldwide. By reframing the question and assembling a team of multidisciplinary experts, the initiative aims to make significant breakthroughs in heart attack prevention. Led by Professor Figtree, the international team possesses the expertise, track record, and determination to succeed. Initial funding is already in place, and negotiations with international research and development programs for additional financing are underway. The success of the COVID-19 vaccine program demonstrated the rapid results achievable through inventive international collaboration among scientists and physicians. Professor Figtree hopes to replicate this success by finding new diagnostic methods and treatment options for heart attack management and prevention. With the goal of benefiting the 18 million people worldwide who die from heart disease each year, we can only hope that they succeed – and succeed soon.

Meet the researcher

Professor Gemma Figtree, AM
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Gemma Figtree is a professor in medicine and chair of the multi-disciplinary Cardiovascular Initiative at the University of Sydney and an interventional cardiologist at Royal North Shore Hospital, a pioneering centre for the treatment of acute heart attack. She has an international track record across a diverse range of fundamental, translational and implementation research areas, and is recognised for her strategic leadership.

Professor Figtree is committed to preventing heart attacks through innovations to detect and treat silent coronary artery disease (CAD). She leads a diverse team unravelling key mechanisms underlying susceptibility and response to heart attack, with studies extending from the bench to large cohort studies and clinical trials. Discoveries in her laboratory have been published in leading journals including the Lancet, Circulation, Journal of the American College of Cardiology and European Heart Journal, with more than 220 publications. Professor Figtree is an investigator on grants totalling more than $42 million. She has an awarded patent and five provisional patents and is the chief medical officer for Prokardia. She is the Chief Scientific Officer of CAD Frontiers, a non-profit venture facilitating collaborations between global clinical, research, policy and industry leaders as an effective platform combining discovery science, clinical trials and commercial translation, with a vision of a world without heart attacks.

Professor Figtree was awarded a National Health and Medical Research Council Excellence Award for Top Ranked Practitioner Fellow (Australia, 2018), NSW Ministerial Award for Cardiovascular Research Excellence (2019) and awarded Member of the Order of Australia (2023). She serves as a member of the Editorial Board of leading international journals including Circulation and Cardiovascular Research and an associate editor for Heart, Lung and Circulation.

Professor Figtree's advocacy work and strategic leadership as president of the Australian Cardiovascular Alliance helped secure Federal commitment to the $220 million Medical Research Future Fund Mission for Cardiovascular Health, which she now chairs. The Mission provides an historic opportunity for a broad range of Australian cardiovascular researchers to work closely with policy makers and healthcare practitioners to tackle major clinical hurdles with translational impact. She is intimately involved in guiding the introduction of diagnostic strategies and management algorithms into clinical practice through her role as chair of the Heart Foundation Heart Health Committee, as well as via regular consultation to the NSW Office for Health & Medical Research and NSW Health (e.g., on the Expert Advisory Group for Premature Cardiovascular Death). She is a co-author of the recent Lancet Commission for Women and Cardiovascular Disease (with initial publication in The Lancet in April 2021). She is a graduate of the Australian Institute of Company Directors and serves as a non-executive Director on multiple community Boards.

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CAD Frontiers
Quest for zero heart attacks

A NOVEL AUTOIMMUNE DISEASE LINKED TO ASBESTOS EXPOSURE

The health hazards associated with occupational asbestos exposure are widely acknowledged and extensively studied. However, emerging evidence suggests that prolonged exposure to environmental asbestos may trigger serious and debilitating autoimmune conditions, although the mechanistic actions remain poorly understood. **Dr Jean Pfau** and colleagues in the Department of Microbiology and Cell Biology at Montana State University, Bozeman, USA, have discovered a novel autoimmune disease linked to a specific type of asbestos, and have conducted extensive research regarding the causes, symptoms, and progression of this deadly condition.

Environmental Asbestos and Autoimmunity

Asbestos is a fibrous mineral which has been used commercially for many years in the construction industry and the production of insulating materials. There are several types of asbestos fibres, which are classified depending on their extraction and fabrication properties. Exposure to asbestos fibres in the workplace is known to have serious health implications, including lung fibrosis and cancers. Fibrosis is characterised by the excessive production of fibrous tissues such as collagen, which gradually replaces healthy tissue with scar-like tissue and eventually interferes with functionality. The realisation of these dangers led to many countries banning the mining and use of asbestos. However, the regulated use and mining of asbestos is still permitted in several geographical regions.

Whilst the causes of asbestos-related diseases have been extensively studied in recent years, research has primarily focused on commercial fibre variations like chrysotile which are mostly encountered in occupational settings and has largely ignored the outcomes of exposure to fibres more commonly encountered in the environment, despite them possessing strikingly similar attributes and posing a risk to health at much lower levels.

Dr Jean Pfau and her esteemed team in the Department of Microbiology and Cell Biology at Montana State University, Bozeman, USA, recognise the health implications of environmental asbestos exposure and have been studying the effects of a specific type of asbestos fibre on the health of residents in the small town of Libby in Montana, with the assistance of colleagues at the Centre for Asbestos Related Diseases (CARD).

The team has discovered that the residents of Libby are prone to developing a uniquely presenting asbestos-related autoimmune condition

Mineral asbestos

with associated collagen thickening of the serum-producing membranes surrounding the lungs. Autoimmune conditions arise when the body elicits a response against its own cells. Dr Pfau and colleagues have endeavoured to elucidate the mechanisms of action preceding the dysfunctional immune response in Libby residents and identify immunological factors that may be predictive of the potential progression and severity of the disease.

Libby: An Environmental Catastrophe

Until the late 1980s, a mine near Libby was the USA's most prolific producer of vermiculite, a mineral used in the construction, motor, and

insulation industries and for germinating and growing seeds. Unbeknownst to the miners, the mineral was contaminated with the needle-like fibres of amphibole (since termed Libby Asbestiform Amphiboles or LAA), and subsequently, residents of the town were exposed to the damaging effects of asbestos for decades via dust, waste products, and playground surfaces. The contaminated mineral was also used to insulate homes, and families were made further vulnerable to exposure via the transfer of fibres on the clothes of returning mine workers. Moreover, the vermiculite was transported and used throughout the country, potentially spreading the asbestos contamination to many more communities. Years later, this exposure was associated with profound health problems in Libby residents, including respiratory and systemic autoimmune diseases (SAID).

Contradictory to recognised asbestos exposure diseases, a deadly and progressive inflammatory fibrotic lung condition was emerging in Libby residents, eventually named Lamellar Pleural Thickening, or 'Libby Disease'. Simultaneously, systemic autoimmune diseases such as lupus and rheumatoid arthritis were occurring more frequently within this population, along with a high frequency of autoantibodies directed against the nucleus of the cell, so-called antinuclear autoantibodies. Taken together, this provoked the notion that LAA may elicit an autoimmune response within exposed individuals and suggested that this altered response may lead to Libby Disease.

Autoantibodies and Disease Outcomes

To this end, Dr Pfau and her team proceeded to investigate whether autoantibodies were able to induce collagen production in serum-producing membranes. Having designed a mouse model to mimic lung tissue and using established laboratory techniques, including cell culture and fluorescence microscopy, the researchers confirmed that certain autoantibodies were indeed present in serum after LAA exposure which were absent in non-exposed counterparts. Simulating an ongoing immune response, the researchers also found that collagen production was significantly higher in the presence of autoantibodies. These findings supported the idea that exposure to LAA induced the production of autoantibodies, and that these exacerbated the fibrotic process via excessive collagen deposits.

Attempting to better understand the increased risk of SAID and to characterise the complex clinical nature of autoimmune outcomes related to LAA exposure, Dr Pfau and colleagues selected several cases from the Libby Epidemiology Research Programme for review. They proceeded to determine the breadth of rheumatological conditions manifesting in Libby residents, and to build a profile of the medical histories of LAA-exposed individuals.

The team found that the prevalence of some SAID, including rheumatoid arthritis and lupus, were considerably elevated when compared to the levels expected in the general population of the USA. However, levels of other non-SAID were not different in Libby residents, suggesting that LAA exposure was indeed responsible in some way for the increased risk of SAID and that the specific lung tissue thickening seen in Libby patients was more likely due to LAA exposure than SAID.

Importantly, many of the rheumatological conditions occurring in the Libby cohort were misdiagnosed owing to the unusual combination of diseases or a failure to meet current diagnostic criteria. The symptoms recurring in these patients included extreme chronic fatigue, Raynaud's phenomenon, rashes, swollen painful joints, and musculoskeletal pain, as well as the lamellar pleural thickening now recognised as Libby Disease.

Immunological Markers for Progressive Disease

General asbestos immunotoxicity usually begins with inflammation, and it is thought that the related autoimmune response is triggered following the activation of various cells of the immune system. Similarly, the effects of asbestos in cell culture and mouse models have been reported as increased DNA damage and programmed cell death. Such early events and cellular interactions may be responsible for the eventual disease outcomes and may be dependent upon the size and composition of mineral fibres. It is clear that many Libby residents have complicated clinical profiles, which pose real challenges for diagnostics and treatment planning, and for this reason, a firm diagnosis may not be reached for several years.

Progressive Libby Disease is characterised by painful scarring and reduced functionality of the lung tissue. Due to these unique manifestations, Dr Pfau and colleagues proceeded to investigate and identify whether any immunological factors were specifically associated with the condition, and which might be useful markers of disease progression and/or severity.

The team conducted experiments using data and serum from those patients at the CARD who met the study criteria. Patients were compared according to their Libby Disease status. The team discovered several interesting immunological traits exclusively associated with progressive Libby Disease, including a significantly higher incidence of particular autoantibodies and increased collagen production. The team predict that this information may aid in the development of combined autoantibody-based screening programmes and highlight novel therapeutic pathways to facilitate early detection and treatment of progressive disease.

Continuing the Mission

Dr Pfau and team describe a novel autoimmune disease exclusively detected in LAA-exposed individuals and have elucidated a potential mechanism of action via increased collagen production, which may also be applicable to other fibrotic diseases. It is apparent that more than one autoimmune disease is associated with LAA exposure, representing a plethora of painful inflammatory conditions and an increased susceptibility to connective tissue disorders. More research is necessary to further characterise this fascinating relationship, and with the team currently working on identifying precise protein targets for LAA-specific autoantibodies, a better understanding of the nature of this devastating disease may soon emerge.

Further work is warranted in order to unravel the mechanisms behind the alterations of self-peptides which lead to the production of autoantibodies, and to increase our understanding of the unusual combinations and temporal alterations frequently observed in Libby residents. This may shed light on potential anti-inflammatory therapies which could aid in mitigating the progression and severity of the disease, to replace the current treatment options, which mainly rely on pain management.

There is no doubt that environmental exposure to asbestos is an urgent public health matter, and the devastating effects which are still experienced to this day in Libby are a grim reminder of the ongoing dangers that this phenomenon poses. There remains a need to raise awareness amongst clinicians working with autoimmune and general inflammatory diseases so that LAA exposure may be recognised at an earlier stage and considered as a possible cause, particularly since it is highly unlikely that this issue remains confined to the Libby area since millions of homes and buildings remain insulated with the material.

The influential research conducted by Dr Pfau and her resolute team will prove invaluable in increasing awareness and education around this terrible affliction, leading to much-needed attention to attract the funding required to continue this vital mission.

Meet the researcher

Dr Jean Pfau
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Dr Jean Pfau received her PhD in Microbiology and Biochemistry from the University of Montana, and has since held several senior positions in highly regarded institutes across the USA. Currently partially retired from Montana State University, Dr Pfau teaches graduate courses in Physiology as well as sitting on several committees and advisory boards. Dr Pfau's research is focused on inflammatory and autoimmune diseases and their environmental triggers, with a particular focus on asbestos exposure in Libby, MT. Indeed, she continues to serve as a consultant with the Centre for Asbestos Related Diseases situated in Libby. Dr Pfau is the recipient of numerous prestigious awards for her contributions to science and also her community outreach and education activities. She has published nearly 60 peer-reviewed papers and has collaborated with distinguished researchers across the world.

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CARD

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Libby Epidemiology Research Program
Agency for Toxic Substances and Disease Registry
Community/Academic Partnership Award (Institute of Translational Health Sciences)

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THE FASCIAL DISTORTION MODEL: A CLINICAL TOOL FOR MUSCULOSKELETAL PAIN

Musculoskeletal pain can be extremely debilitating and although common, it can also be difficult to treat. **Dr Joshua Boucher**, an osteopathic physician based at Southeast Alaska Regional Health Consortium, is working to show how the Fascial Distortion Model (FDM) can alleviate the pain and decreased function associated with musculoskeletal injuries. His encouraging findings are establishing the FDM as a useful clinical tool, and more research is already underway.

Musculoskeletal Pain and Fascia

Musculoskeletal pain can affect bones, joints, ligaments, tendons, muscles, and fascia. The causes vary from injury to long-term health conditions. Affected individuals report often persistent pain and limitations to their mobility and dexterity, impacting their ability to live a full and productive life. The World Health Organization estimates that globally, approximately 1.71 billion people suffer from musculoskeletal conditions of some form, meaning they represent a leading cause of disability.

Common musculoskeletal injuries include bone fractures, sprained ankles, and tendinopathies. The Fascial Distortion Model (FDM) by the American physician, Dr Stephen Typaldos, proposes that musculoskeletal injuries are the result of damage to fascia – the connective tissue that lies beneath the skin. This thin, stringy tissue is mostly made of collagen and wraps around each and every organ, blood vessel, bone, nerve fiber, and muscle in our bodies. When healthy, fascia provides us with the support, stability, and flexibility we need to move. But it can go wrong…

When Fascia is Damaged

The FDM describes six different fascial distortions (or diagnoses) that can occur when fascia is somehow damaged. The most common is a triggerband, in which the fascia becomes wrinkled. Herniated triggerpoint occurs when soft tissue pushes through the layers of fascia. Continuum distortion refers to the alteration of fascia between two different tissue types. In a folding distortion, the fascia has become contorted as the result of pulling or pressure such as twisting. Cylinder distortion is the term used for tangled coiling of the fascia, and finally, tectonic fixation occurs when the fascia cannot glide in its plane. Specific diagnoses are made based on how the patient describes and demonstrates their pain.

Dr Joshua Boucher, previously of the Dwight D. Eisenhower Army Medical Center, William Beaumont Army Medical Center, and now of the Southeast

Alaska Regional Health Consortium, became familiar with the FDM during his medical training and quickly saw its untapped potential. He completed full training at the FDM Academy and became internationally certified through the American Fascial Distortion Model Association and now works to advance the field through research and education.

A Case Study – with Impressive Findings

In 2018, Dr Boucher published one of his early applications of the FDM in the Journal of Osteopathic Medicine in collaboration with Dr Jose Figueroa, of the Des Moines University College of Osteopathic Medicine in Iowa. This was

a single case study of a patient with 'frozen shoulder' – so called because of the stiffness and pain that limits the individual's range of movement. The symptoms can last for months and even years and while recovery may sometimes occur without treatment, this process is likely to be prolonged and the full range of motion may not ever be fully restored. Conventional treatment approaches include painkillers, anti-inflammatory drugs, and physiotherapy.

On encountering a 28-year-old male with frozen shoulder that had not responded to conventional self-treatment at home with medication and exercise, Dr Boucher recognized that the FDM might be an effective alternative. The pain had remained constant since the injury 18 months before, and the limitation to movement typical of the condition had progressively worsened over time, limiting the patient's ability to conduct day-to-day tasks and even play with his children.

Osteopathic examination confirmed that the shoulder pain resulted from a hyperextension injury, in which the joint had been forced to move beyond its normal range of motion. Dr Boucher identified three fascial distortions of the shoulder: Herniated triggerpoint, triggerband, and folding distortion. Initial treatment of firm pressure using the FDM resulted in immediate benefits, with the patient reporting improved movement and reductions in pain on completion of this first intervention. He attended for a follow-up appointment two weeks later, during which Dr Boucher applied the FDM intervention again, this time resulting in the full restoration of movement and complete removal of pain. Three months later, the patient happily confirmed his complete recovery and the resumption of daily activities.

While the application of the FDM can result in temporary discomfort for both the patient and the practitioner during the manual procedure, the outcomes of this case study were certainly impressive, and confirmed the potential of the FDM as a noninvasive and alternative approach to managing musculoskeletal injuries.

Delving Deeper into Why

Encouraged by these findings and his work as a military physician in which he repeatedly saw the effectiveness of the FDM, Dr Boucher wanted to understand more about how and why the FDM could be so effective.

One condition that he frequently treated in his work was plantar heel pain, which occurs on the bottom of the foot (also known as plantar fasciitis). He discovered that it is possible to measure the thickness of the plantar fascia to track objective changes in the condition over time. Seeing that this could provide direct evidence of improvement as a result of treatment for plantar heel pain, Dr Boucher knew he could now delve deeper into the effects of the FDM.

During the intern year of his Family Medicine residency, Dr Boucher started the long and difficult process of requesting institutional review board approval to conduct this research, supported by his mentor, Dr Scott Mooney. Never in the USA had the FDM been studied on a large scale before and thus, safety data were limited – which made it difficult. But after nearly a year, the required approval was received, and the researchers started the study.

Objective Evidence of Improvement

The participants were full-time military personnel who reported heel pain for at least 30 days and also had a clinical diagnosis of plantar heel pain. Dr Boucher used the FDM diagnostic and treatment strategy to identify fascial distortions according to patient-reported pain patterns and examination. He applied the therapy at this point and again one week later with a total of 28 participants.

Once again, the results were impressive, showing significant and sustained improvement on a range of validated measures of pain and physical function. But most critically, the thickness of the plantar fascia was reduced, as assessed by ultrasound at the beginning of the study and follow-up at 16 weeks. The ultrasound was conducted by a radiologist 'blinded' to each participant's status in the study, meaning the interpretation of the scans was free from any potential bias.

Although small, this study represents an important milestone for the FDM. Building on clinical observation and subjective reports of benefits from participants, this study confirmed that the benefits could be directly and objectively observed.

A Solid Foundation for Further Research and Progress

Dr Boucher isn't stopping yet and he believes there is much more to learn about the FDM. He is currently working on two survey-based studies and notes that we still have little data on the side effects, safety, and effects of the FDM in other musculoskeletal conditions. These are important gaps to fill in the near future.

Nonetheless, the findings from Dr Boucher suggest that compared to other interventions, the FDM is relatively inexpensive, least invasive, and can lead to the fastest onset of recovery for musculoskeletal pain. Having provided a solid foundation on which to build, he is committed to advancing and pioneering FDM research further.

Having personally observed the impact that the FDM has had on his patients, Dr Boucher is working on becoming a member of the FDM Academy to help teach the FDM across the USA. You can learn more about the courses at https://afdma.com/ and https://www.thefdmacademy.com/

Meet the researcher

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Dr Joshua Boucher is an osteopathic physician based at the Southeast Alaska Regional Health Consortium. In 2012, he received a bachelor's degree in Biology from Utah State University, and in 2016, graduated from the Osteopathic medical school Des Moines University. He was awarded a full ride scholarship to medical school through the Health Professions Scholarship Program which required him to serve four years in the United States Army after finishing his residency. In 2019, he graduated from a family medicine residency at the Dwight D. Eisenhower Army Medical Center. That same year, he became boarded in family medicine, and as Captain in the United States Army, became the Medical Director at the Soldier Family Medical Clinic at Fort Bliss Texas. Shortly after, he was assigned to be the pain champion and since then, has mentored many military providers in the Fascial Distortion Model (FDM). In 2020, he was moved into the Officer-in-Charge position where he managed a primary care clinic and that same year, was hired as an adjunct faculty member at the Burrell College of Osteopathic Medicine. He is a Director-at-Large for the American Fascial Distortion Model Association where he leads the research committee. In addition to research activities that include mentoring researchers and organizing national research competitions, he has published several peer-reviewed medical articles.

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UNDERSTANDING THE TRANSFER OF NON-GENETIC INFORMATION FROM PARENTS TO OFFSPRING

The transfer of genetic information from a parent to their offspring via deoxyribonucleic acid (DNA) is fundamental for the survival of a species. Evidence is emerging that epigenetic information – information independent of underlying DNA sequence – can also be transmitted to offspring and that parental environment can alter epigenetic information and influence the characteristics of future generations. **Dr Upasna Sharma's** work as a postdoctoral researcher at the University of Massachusetts Chan Medical School discovered a previously undescribed mode of epigenetic inheritance in sperm, and provides evidence that paternal diet can influence the descendants' metabolic state via epigenetic mechanisms.

The Evidence for Epigenetics

Whilst it is accepted that genomic deoxyribonucleic acid (DNA) is responsible for most of the inheritance from parent to offspring, there is increasing evidence that information unrelated to the DNA sequence is also passed on to future generations, and furthermore, that the environment to which the parents are exposed can influence the attributes of their offspring. The dietary habits of the father, for example, can alter how offspring synthesise metabolic compounds.

Dr Upasna Sharma and colleagues in the Department of Biochemistry and Molecular Pharmacology at the University of Massachusetts Chan Medical School, USA, report intriguing findings regarding the influence of paternal diet on the constituents of sperm during the maturation process. They have now deciphered a mechanism via which these constituents are transferred into the sperm from somatic cells.

The Effect of Paternal Diet

Ribonucleic acid (RNA) is an omnipresent substance which contributes to the implementation of a wide range of bodily functions and exists in different forms, including transfer RNA (tRNA), a small molecule with a role in protein synthesis. However, pieces of tRNA which have an alternative purpose may also be present in cells such as sperm.

A growing body of evidence suggests that parental environment can affect the metabolic health and physiology of their offspring in a phenomenon known as the intergenerational inheritance of acquired traits, or epigenetic inheritance, although the mechanisms

by which this occurs are poorly understood. Indeed, until recently, the theory of intergenerational inheritance was all but dismissed due to a lack of explanation regarding the potential mode of action and the presumed inability of somatic cells to transmit information to germ cells.

Though notoriously tricky to demonstrate, Dr Sharma and her colleagues endeavoured to investigate non-DNA driven inheritance via sperm and the possible ways in which this might happen. They began by determining whether paternal diet

could indeed influence the metabolism in offspring generated by in vitro fertilisation. The group used sperm from mice who were fed a low-protein diet and found that their descendants displayed altered hepatic cholesterol biosynthesis in comparison to regular-diet controls, thus confirming their hypothesis. These findings also corroborated their previously published work.

Small RNAs are implicated in a variety of non-genetic processes and are one of the most established carriers of epigenetic information. For this reason, the team proceeded to examine the presence of small RNAs within mature mammalian sperm. They discovered an abundance of fragments generated by the cleavage of non-coding tRNAs (tRFs) which were further upregulated in the sperm of mice consuming a low-protein diet. Further analysis revealed very low levels of tRFs in the testes and immature sperm, raising the question of when exactly the sperm acquire these tRFs.

The Maturing Sperm

After leaving the testis, sperm complete their maturation whilst travelling through the epididymis, a long, convoluted, tubular organ in which the concentration of tRFs increases between the entry point (caput) and exit point (cauda). During this transit, the sperm fuse with small vesicles called epididymosomes which exhibit a pattern of small RNAs like that seen in cauda sperm. This prompted Dr Sharma and the team to speculate that epididymosomes transfer tRFs into the sperm during the maturation process. Analysing immature sperm which had been incubated with epididymosomes isolated from the cauda did indeed show that fusion occurred, resulting in delivery of tRFs.

Interfering with the function of specific tRFs in an embryonic stem cell model resulted in dramatic changes in gene regulation, with some of the most prominently activated genes also known to be highly expressed in preimplantation embryos. To this end, Dr Sharma and colleagues investigated whether embryos derived from low-protein diet sperm, which carry higher levels of tRFs, affected the same target genes. Using mature sperm from low-protein diet mice or injection of specific tRFs in control embryos, they were able to determine that embryonic gene expression was altered in both cases, hence concluding that gene regulation in early embryos is influenced by sperm tRFs.

Most interestingly, embryos derived from low protein diet sperm demonstrated delayed development in comparison to controls, and this may be partly associated with the vital role that sperm small RNAs play during implantation and early embryonic development.

Small RNA Dynamics

Having made these remarkable discoveries, in addition to confirming their initial findings regarding tRF delivery via the epididymal cells, Dr Sharma and the research team determined that the RNA payload in sperm switches from one type of small RNA to another after exiting the testis.

It is widely accepted that small RNAs have a key role in gene regulation, as demonstrated in several animal models including mammals. Small RNAs exist in a variety of biodiverse forms which each possess a unique regulatory function; for example, piRNAs are deemed essential for silencing the transposable 'jumping' elements in the genome and comprise the main small RNA population in the testes and testicular sperm populations.

Exceptionally low levels of tRFs are detected in testicular sperm, which suggests that sperm only gain tRFs upon entry into the epididymis. The fact that tRFs make up only around 2% of testicular RNAs but are the most abundant form in mature sperm from the epididymis piqued the interest of Dr Sharma and colleagues, inspiring them to investigate the temporal dynamic processes involved in the gain and loss of small RNAs from sperm during epididymal maturation.

Samples containing sperm of varying maturity were extracted from both the testicular and epididymal regions and assessed for their RNA content after washing with a previously validated method. Following this, sperm were physically separated into heads and tails to evaluate the subcellular location of small RNAs. Tails were found to be highly enriched with piRNAs, and whilst tRFs were more equally distributed between tails and heads, some tRFs were moderately more abundant in heads, suggesting that a subset of small RNAs can be transmitted from sperm to oocyte at fertilisation. These findings provided a more detailed insight into the distribution of small RNA populations in the sperm and male reproductive tract and laid strong foundations for further exploration.

Next, small RNA dynamics in various germ cell populations in testis and epididymal sperm were examined by sequencing small RNAs. Interestingly, a consistent decrease in the overall levels of piRNA was observed as the sperm moved from the testis to the epididymis, followed by an extraordinary increase in tRFs in the caput and cauda sperm. This suggested that the remodelling of the small RNA payload in post-testicular sperm is attributable to a combination of piRNA degradation and tRF gain, which continues throughout the epididymal journey.

One curious occurrence observed during these elegant experiments was the seemingly undulating concentrations of certain small RNAs in different regions of the reproductive tract, with a marked reduction seen in caput sperm compared to testicular and cauda sperm, implying that small RNAs are lost upon exit from the testis and replenished by epididymosomes in the epididymis. Complex molecular cell tracking procedures confirmed that at least some of the small RNAs present in mature sperm are synthesised within the somatic caput epididymis epithelial cells.

Next, using elaborate laboratory techniques, Dr Sharma and her research partners deduced that the small RNAs carried by mature cauda sperm were first manufactured in the epididymal epithelial cells prior to transfer into the sperm via epididymosomes, thus verifying their earlier findings and reaffirming a unique interaction between somatic and germ cells to facilitate the delivery of small RNAs into post-testicular sperm.

Predicting Inheritance, Treating Disease?

In a recently published comprehensive review, Dr Sharma, now heading her own independent laboratory at the University of California Santa Cruz, succinctly summarises the latest developments in this emerging area of research, and explores some of the concepts, evidence, and mechanisms involved in intergenerational inheritance driven by small RNAs in sperm, much of which validates Dr Sharma's findings.

Certainly, this fascinating work has demonstrated that paternal diet plays an important role in regulating the epigenetic composition of sperm, and that information inherited by the offspring can alter their observable characteristics. Furthermore, the discovery that epididymosomes deliver tRFs into the sperm constitutes the identification of a now patented mechanism of action for the transfer of small RNA fragments from somatic cells into germ cells and describes a novel epigenetic reprogramming event not previously observed during mammalian spermatogenesis.

Dr Sharma's current research aims to understand the molecular basis of selecting, sorting, and packing small RNAs into epididymosomes that could reveal the precise mechanisms of cell-cell communication and may increase our knowledge regarding the way in which environmental information is signalled to sperm for ultimate transfer to offspring. Moreover, this might help to explain how changes in environmental conditions lead to tRF modifications and stability. Vitally, understanding the mechanism of intergenerational inheritance and its contribution to metabolic conditions in progeny may prove invaluable in the study and treatment of common metabolic diseases, such as diabetes.

Meet the researcher

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Dr Upasna Sharma received her PhD in Molecular Biology and Biochemistry from Wesleyan University, Connecticut, and proceeded to complete her postdoctoral training at the University of Massachusetts Chan Medical School. Currently, Dr Sharma holds a post as Assistant Professor of Molecular, Cell, and Developmental Biology, and heads her own research laboratory. The primary focus of Dr Sharma's intriguing research is to investigate the mechanisms underpinning epigenetic inheritance from parent to offspring, and the implications this may have for future generations. In addition to acquiring an impressive portfolio of grants to support her work and acting as a reviewer for international grant agencies and several high-impact journals, Dr Sharma is the recipient of many prestigious awards and has contributed immeasurably to the field of reproductive tract biology and preimplantation development.

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EDUCATION & TRAINING

A SUMMER OPPORTUNITY PROGRAMME FOR ASPIRING SCIENTISTS – WITH A DIGITAL TWIST

The development of a talent pool in Science Technology Education and Medicine that is as diverse as our population, has been a difficult goal for decades. Increasing the diversity of scientists from underrepresented communities can drive both innovation and creativity within the sciences. The Molecular & Environmental Toxicology Centre at the University of Wisconsin-Madison, USA, has run a summer research opportunity programme since 2011, providing scientific experiences and promoting scientific careers in the environmental health sciences for aspiring young people from backgrounds historically underrepresented in this field.

Developing a Diverse Scientific Workforce

The USA is home to some of the most prestigious and well-funded universities and research institutes in the world. As such, there is strong competition for scientific positions at these institutions. While many scientific opportunities exist, they may not be equally as accessible to all.

Many factors can contribute to a recent undergraduate not being fully prepared/competitive for graduate studies or other scientific positions. Students may not be aware of or have opportunities to access cutting edge research laboratories or they may attend colleges with fewer resources for hands on laboratory experiences. Further, students may not always know that research is something they want to do in the future. This is particularly true for first generation students who are not as familiar, and don't have the support of family members or mentors who know the process of applying for graduate school and what might look good in a graduate research application.

This contributes to a lack of diversity within graduate training programmes in Science Technology Education and Medicine (STEM) careers. In turn, the lack of diversity in training programmes can lead to many underserved populations not seeing these professions as available or welcoming to them; they may see the scientific field as a 'gated community' that only allows certain people into its ranks. In addition, a lack of scientific training opportunities for our entire population leads to fewer scientists overall and unfilled professional positions. These consequences are not unique to the USA; a quick look at the official website for UK Immigration Services shows that professionals with biochemistry and biological science backgrounds rank high on its 'Shortage Occupation' list.

What is the problem here? Why is it that countries, home to some of the oldest and most prestigious universities in the world, fail to generate talent or junior scientist pools that are reflective of the diverse populations they serve? Moreover, have these same countries recognised that the most pressing environmental issues facing our world, including plastic pollution, climate change, and the potential emergence of new infectious diseases, are likely to require creative solutions generated by the previously untapped potential of individuals who may not currently see a path to enter the scientific workforce?

This need for a generation of scientists from varied backgrounds and representing a diversity of thought is likely to exist worldwide. To answer the scientific challenges of tomorrow, there needs to be a greater and more diverse pool of young scientists from which to produce our future scientific leaders.

The answer to this problem may be complex but one initial step appears to lie in the increased access to early-career scientific opportunities for students from underrepresented communities. A specific example includes an increase in experiential programs at major research institutions to both draw new populations into scientific research and provide essential early exposure to science and state-of-the-art technology. Importantly,

such an effort can be part of a more holistic approach, as over the long-term, its success can reduce the stereotypical images of unfamiliar scientists superimposed over unfamiliar instrumentation or data forms. Unsurprisingly, such stereotypes may not 'sell' scientific career paths to all ambitious university graduates, and especially not to those from underrepresented backgrounds.

A Touch of History

In efforts to increase diversity within STEM, universities are developing outreach activities to entice all talented young people into careers they may not have previously considered. The University of Wisconsin-Madison's Molecular & Environmental Toxicology Centre (METC) is an early adopter of this strategy. Every summer, they host a small group of aspiring young people from all over the USA and Puerto Rico so they can get a taste of life in a scientific career and explore whether this is a viable future for them.

This programme, the METC-summer research opportunity programme (METC-SROP), ran for the first time during the summer of 2011 after gaining external funding from the National Institute of Environmental Health Sciences. Since its inception, MET-SROP has recruited students from underrepresented communities, including those who identify as Black, African American, Hispanic, Latino, Native American, Alaska Natives, Native Hawaiians, and Pacific Islanders. As the National Institutes for Health evolved their definition of 'underrepresented', the programme also encouraged those from a disadvantaged socioeconomic status, those with a documented disability, and those who are the first in their families to attend a university. While the programme focused on students currently in college or university, the selected participants were often chosen because they may not have access to a research experience at their institutions of study or their institution might not have a focus on environmental health science.

Under usual circumstances, the MET-SROP selects between 6 and 10 students each year. These participants move to the University of Wisconsin Campus for the summer, where they are housed in a dormitory setting adjacent to campus. Here, the participants build a community of fellow scientists and spend 10 weeks in a research laboratory, conducting their own research with extensive support from dedicated faculty members. In addition, each trainee is assigned a close mentor, who is typically a graduate student in the Molecular & Environmental Toxicology Graduate Program or a field related to each student's interest.

Their projects are designed with two main goals: to gain scientific competency with hands-on tasks and to provide participants with their own, real-world research data set. The latter aspect is often the most impactful, as it allows students to gain insight into data structure, analysis tasks and interpretation. The projects are widely varied and attempts are made to match students' interests. These include but are not limited to topics in biochemistry, molecular biology, and environmental sciences. The multitude of available projects allowed students to choose a topic they personally find interesting, providing further motivation to succeed.

Working in research laboratories can be difficult, even at the best of times. Experiments have a tendency to go wrong or bring unexpected results. Guiding a group of fledging scientists, some of whom are entering a laboratory environment for the first time, to successfully complete ambitious objectives, takes a remarkable amount of forward planning, patience and dedication. Yet, past success is an indication that the necessary planning and training is sufficient to support success. Since the beginning of this effort, 124 students have benefited from a summer experience at the METC-SROP. Of those that have come through the programme, more than half are now either studying in university graduate programmes or now have an advanced degree in science, medicine, or other related professions. This is a considerable marker of success, especially

considering how students from underrepresented communities are currently not well represented in the biological sciences.

Back to the Drawing Board

Then, early in 2020, COVID-19 struck. Because of the many unknowns related to the disease, normal working conditions ceased and all travelling was put on hold. One of the effects that this had was the day-to-day operations at universities. Classes were moved into an online (virtual) format and in-person operations were suspended, including those for important programmes. The university's closure of face-to-face instruction left the future of the METC-SROP programme hanging in the balance. The programme needed to develop an alternative approach that could be delivered in this rapidly emerging new age of online lectures and Zoom calls. To provide this SROP in uncertain times, the planned programme was retooled around five criteria:

1. Replicate the sense of a scientific experience at a major research university
2. Provide a challenging research project
3. Promote an understanding of how the environment affects human health, especially for underrepresented communities
4. Facilitate the development of skills that students could utilise in a future scientific career
5. Promote the University of Wisconsin-Madison as a desirable choice for further research training

The Shape of Things to Come

The team discussed potential innovative strategies and evaluated which elements of the programme could be made available online, together with additional, complementary features. Following two months of intense planning, the team agreed to run the programme virtually.

One of the most crucial elements would be whether or not the participants had reliable access to participate in a summer virtual experience from various locations across the continent. Through follow-up calls, methods were developed to ensure that bandwidth was available for students from a variety of geographical locations. This included connections through their internet service provider or their cellular services. The programme was prepared to provide laptops but that was not needed, as the participants had become prepared through the prior months of adjustment to a virtual classroom at their undergraduate institutions. In fact, they were excited and ready to continue in this virtual world for their research experience.

With evidence that all members of the programme – leadership, participants, and instructors – could be successful in this virtual environment, the appropriate platform was identified. By hiring all participants as remote University of Wisconsin-Madison employees, each trainee was provided access to a variety of communication options, with which the university

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held contracts. The three most prominent platforms used at the time were WebEx, Zoom, and Microsoft Teams.

Following discussions and trial runs, the Teams platform was chosen as a primary venue because of its adaptability for a more 'classroom' feel. To enhance continuity, a channel was created and all members of leadership, instruction, and the participants were invited to join. This software allowed easy saving of files, a more intuitive platform for all-day events, individual break-out rooms for participants and advisors, and the availability to save conversation/discussions.

The first module of the redesigned course – Learning the Basics – was a series of formal daily lectures covering how toxicants enter the body, how they act, and how they are eliminated. This also included problem sets to help participants actively learn the concepts. The second module – Skills for Research Success – introduced students to information searches in the scientific literature, concepts of data analysis, and scientific communication. This included practice in the writing of research papers, the development of poster presentations, and the crafting of scientific talks. Since the module also included a presentation task, participants received training in presentation skills. Each student selected a particular chemical, researched the literature on its toxicity and presented their findings to the student cohort.

These tasks not only allowed students to apply learning to practice but also helped them build confidence in presenting data confidently and rigorously. The programme finished with the 'Toxicology Research without the Lab' module. Here the initial focus was on learning the principles of a widely used programming language for statistics and data analysis, R, an invaluable skill in all areas of scientific inquiry.

During the final two weeks, utilising all their recently acquired skills, participants prepared a final presentation. However, this time the stakes were higher: the audience included 40 scientists from around the university, including faculty, postdoctoral trainees, and graduate students, as well as some of the off-

campus instructors that provided training opportunities. While nerve-racking for many, this component was the high point of summer – a very good test of skills and demonstration of achievements and confidence.

Some Losses, but Also Major Gains

During the programme, participants worked virtually alongside scientists and interacted daily with research students already at the university through the Teams platform. While the close relationships with role models were unique because they were created online, numerous efforts were made to create community. The most important step that was taken was that at least one member of the leadership team (but often more) attended all meetings. This demonstrated their commitment, both to the participants and to the programme.

In addition, participants were paired with current students within the graduate programme. This happened midway through the summer as they began to look at topics for their final research presentations. The pairing was based on an array of criteria, including but not limited to, research interests and home state/community. Pairs were given time to interact and only they were provided access to specific breakout rooms to ensure there was no confusion about who was working with whom. The interaction with the graduate students turned out to be highly productive and satisfactory for the participants.

The virtual programme brought considerable benefits during the times of a worldwide pandemic, both for participants and those running the modules. The online programme places more emphasis on gaining familiarity with computational skills necessary to conduct modern research. Participants also engaged in didactic learning in toxicology and professional training for the first time in the history of the programme. The breadth of this training demonstrated to participants the formal university-like lectures and small group teaching sessions of graduate study, features that prepare students well for a future at university.

Another remarkable bonus of the digital format was that some teaching sessions were delivered by world-renowned scientists working at other universities. Before the pandemic, it was unheard of to have a prominent guest speaker deliver a seminar 'remotely'. Commonly, there would be a formal invitation and weeks (if not months) of planning and coordination and all of this occurred at a considerable financial cost.

The utility of virtual platforms, as well as the greater availability of speakers because of a world under lockdown fortunately increased access to inspirational speakers. The reduced logistical burden of online symposia also provided greater opportunities for participants to ask questions of distinguished scientists that would not have been possible during times of less innovation and flexibility (the pre-COVID-19 world). Because of the newly accepted use of virtual meetings

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and lectures, the METC-SROP was able to capitalise on the incorporation of alumni, colleagues, and other experts by sending invitations as little as one week in advance, as these speakers did not have their usual in-person obligations (because of working from home) nor did they require the travelling and logistical requirements that are associated with guest and expert speakers and their travel.

Those delivering the programme also spotted notable benefits. The organisers found that some of the online lectures could be delivered by current university students and alumni from around the world, who also delivered virtual small group training sessions and interacted with the participants of METC-SROP online. These activities had the added benefit of preparing the university's own present and past scholars for a future career in teaching at university level and helped them develop the necessary skills to inspire the next generation of budding scientists.

As a result of the COVID-19 pandemic, the METC-SROP leadership came away with the blueprint for a successful online education programme in the future. Moreover, as a result of this success, online courses will represent a valuable educational tool even after the pandemic subsides. In coming years, the METC-SROP will not only deliver more virtual educational content, but can also use these tools to bring in additional scholars and teachers, encourage interactions, and build greater relationships between participants and those running the course. This puts the University of Wisconsin-METC at the forefront of online education and provides an example that other universities, and other educational institutions, may find of use.

Meet the researcher

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Postdoctoral trainee Emmanuel Vazquez-Rivera received his bachelor's degree from Universidad del Esta (Carolina) in 2010 and his PhD from the University of Wisconsin-Madison in 2019, where he validated the use of yeast as a model organism to study the aryl hydrocarbon receptor. He continued his postdoctoral training, studying mercury methylation utilising metagenomics and transcriptomics. In addition, he has recruited and trained undergraduate and doctoral students, especially those from underrepresented communities. Seeing this as his passion, he hopes to gain a permanent position, utilising skills learned from this and other training opportunities to prepare the next generation of scientists for biomedical breakthroughs.

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THE BIOMEDICAL ENTREPRENEURSHIP SKILLS DEVELOPMENT PROGRAM (BEEP): EDUCATING A NEW GENERATION OF MEDICAL INNOVATORS

Innovative, new technologies are rapidly being introduced into the medical world, as scientists and inventors continually discover solutions to all kinds of health issues. However, comprehensive education in medical product development, business process and strategy is distinctly lacking for science students who aspire to become commercial medical innovators and entrepreneurs. Entrepreneurially minded professionals at the New York University Grossman School of Medicine developed, implemented, and integrated programs to train early scientists in the business side of science to accelerate the pace of commercialisation and encourage individuals to pursue venture creation and entrepreneurship to impact highly relevant healthcare solutions.

Filling an Important Gap in Biomedical Education

The exciting world of medical technology and digital health solutions is expanding at a rapid rate, bringing with it innovative and ground-breaking solutions to all sorts of medical conditions. Underpinning these new therapies is a solid grounding in the sciences, especially biomedical science. However, releasing novel technology into the world requires more than a researcher's scientific knowledge; it requires a business savvy that is not always taught in scientific and medical degree programs.

To fill this important gap, a collaborative group of experts in biomedical entrepreneurial education at the New York University Grossman (NYU) School of Medicine created an academic program called the Biomedical Entrepreneurship Skills Development Program (BEEP), supported by an R25 Educational Grant from the National Institute for Diabetes and Digestive and Kidney Diseases (NIDDK). One professional playing a key role in the implementation of this important program is Dr Gabrielle Gold-von Simson, who explains 'Our mission is to accelerate the pace of commercialisation of biomedical inventions and discoveries by supporting postdoctoral students, undergraduate and graduate students, and faculty in launching new ventures.'

BEEP integrates the resources at NYU, the NYU Grossman School of Medicine, and the NYU Clinical Translational Science Institute (CTSI) to provide mentoring, expert analysis, and networking along with support in market research, product definition and business model development to help students advance their ideas and become more proficient in the business side of science. This assists participants

to take their scientific knowledge and research and apply it to the development of well-designed, practical health solutions and commercial ventures that will positively impact people with disease. Furthermore, enrolling and retaining participants from underrepresented groups to improve their access and retention in research, science, technology, and healthcare is a key goal.

The initial evaluation and feedback to date regarding BEEP are both overwhelmingly positive. Dr Gold-von Simson explains, 'Evaluations show significant increases in self-assessed knowledge. We believe that this knowledge and the added confidence that it instils (as seen by evaluating participants' attitudes towards entrepreneurship) will in turn make programme graduates attractive and competitive candidates for many positions in the biomedical industry, both in new ventures and at more established companies.' To further test the impact of their work, Dr Gold-von Simson and her colleagues will initiate long term surveys that will track participants' career development over several years, and they plan to report back on this in due course.

Translational Pathways for Cardiovascular Devices: Online Course

A new and unique collaborative element of the BEEP program was recently introduced into the programme. This multidisciplinary collaboration brings together experts in biomedical product development from different universities and will further enable the cross-pollination of ideas. Dr Nabil Dib (President of the International Society for Cardiovascular Translational Research) and other colleagues with extensive expertise in the development of cardiovascular devices designed and implemented the in-depth online course and e-book.

Dr Dib saw that less than 10% of medical start-up companies succeed, and this is often due to a significant educational gap in medical product development and innovation. As such, he wanted to provide a course with educational materials to teach how medical products are produced, and to clearly outline each important step. This translational pathway self-paced course explains the standardised process of medical product development from the beginning (identifying unmet patient needs) to the end (providing a therapeutic to patients). Experts from the Food and Drug Administration (FDA) including the Director of the Cardiovascular Devices Division, Dr Bram Zuckerman, experts from the European Commission, and world industry leaders all contributed to this comprehensive course to ensure each aspect was approved by a relevant specialist.

The Translational Pathways for Cardiovascular Devices course involves eight different online sessions which contain topic talks from experts, ranging in length from five minutes to forty minutes. Following each session, panel discussions are available to enhance and consolidate the information given during the section. In total, the course contains 25 hours of educational material provided through 80 multidisciplinary lectures presented by the innovators, industry leaders and regulators who helped create it.

Session One is titled Basic Knowledge on Medical Devices Development and provides a general overview through thirteen different topics. These topics ensure each student has a solid understanding of the translational pathway for cardiovascular products. Starting at unmet patient needs, students learn how to choose a concept and create a product from this. This requires knowledge of intellectual property, business planning, regulatory procedures, reimbursement and practice guidelines. Students are then taught about preclinical trials and evaluation, often necessitating animal models. These trials are used to assess the early feasibility of their medical product to see if it can move onto clinical research.

The knowledge of translational biostatistics is critical to collect the evidence through the product development, to which the course dedicates a long topic. Understanding common study design, sample size, evaluation methods and more is essential for the students to evaluate their ideas. Once a product produces promising results, regulatory approval is needed to roll it out and market it, so the talks on this topic are given by regulatory experts from the FDA and European markets. The students then learn about the adoption of their potential technology, the implications their translational research can have and any conflicts of interest. Session One concludes with the patients' voice, where students can reflect on the people that they are aiming to serve through their innovations.

Translational Pathways for Specific Cardiovascular Technologies

The subsequent sessions of the course are focused on the

translational pathways for specific cardiovascular technologies so the students can see how their teaching from the first session could be, and is, applied in real-world situations. Beginning with an explanation of the clinical need for each cardiovascular treatment device, the sessions move on to describe the methods and endpoints of their development, the current challenges and their future direction from an industry point of view. Some sessions also review the progress of a specific technology through its clinical trials and beyond.

Session Two is dedicated to the Translational Pathway for Transcatheter Aortic Valve Replacement. This is a surgery that involves the replacement of aortic valves in the heart that have narrowed and fail to open properly, reducing normal blood flow. This is followed by Session Three: Translational Pathway for Transcatheter Mitral/Tricuspid Valve Devices and then Session Four: Translational Pathway for Coronary Stent.

Coronary stents are a life-saving and widely-used technology that open up coronary arteries that have been blocked or narrowed due to atherosclerosis (thickening or hardening of the arteries). The procedure requires the insertion of a balloon into the blocked vessel, which is then inflated to increase the space within. A wire-mesh tube, known as a stent, is left in place in the artery to facilitate blood flow long after and prevent future heart attacks and reduce angina (chest pain).

Session Five of the course delves into the Translational Pathway for Catheter Ablation, Session Six covers Translational Pathway for Ventricular Assist Devices, and Session Seven focuses on the Translational Pathway for Interventional Devices for Heart Failure. These devices are implanted into patients who have suffered from irregular heartbeat rhythms and/or heart failure and the varying types carry out specific functions. For example, pacemakers are given to patients whose hearts beat too slowly (less than 60 beats per minute) due to a condition called bradycardia. The pacemaker generates electrical pulses that make the heart pump at a regular rate. Similarly, implantable cardioverter defibrillators can sense if the heart is beating too quickly due to heart disease, heart failure or genetic arrhythmias. The device creates an electrical shock which puts the heart back into a normal rhythm.

The final session, Session Eight, discusses the Translational Pathway for Left Atrial Appendage Closure Devices. These devices are an alternative to long-term anticoagulation (anti-clotting) drugs which can have negative side effects like bleeding complications for many patients. In a somewhat surprising procedure, a plug is placed in the left atrial appendage of the heart to prevent blood flow to the area. This is because blood clots form here in about 85% of cardiovascular clotting events and blocking off the section appears to reduce the risk of stroke to the same extent as drugs but without the risk of bleeding complications.

As the students understand the strategies and processes needed for medical innovation and see how they can be applied to existing technologies, they are challenged to consider how they might contribute to the field in the future. The pioneering education they receive pushes them to think creatively yet practically. With the addition of this multi-institutional self-paced course, specific to device venture development, the BEEP is greatly enhanced and can better provide a more immersive experience to early researchers in the biomedical field interested in product development, venture creation, and entrepreneurial partnerships.

These innovative and collaborative efforts to educate and engage promising inventors have and will continue to expedite new scientific discoveries and their translation to effective therapies for patients. In the not-too-distant future, programmes like BEEP that incorporate collaborative learning opportunities such as the highly innovative course, Translational Pathways for Cardiovascular Devices, will encourage early-stage scientists to pursue their ideas for biomedical commercial ventures that can decrease medical costs, reimagine healthcare solutions, and ultimately, save lives.

Meet the researchers

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Dr Gabrielle Gold-von Simson is an Associate Professor of Pediatrics at the New York University Grossman School of Medicine and holds an MD and MSc in Clinical Investigation from the same institution. She is the Principal Investigator on an R25 NIDDK-funded educational grant to support BEEP. She is also the Director of the Clinical Research Center and the Program Director for the Health Innovations and Therapeutics Track/ Program.

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Dr Nabil Dib completed his Interventional Cardiology Fellowship Program at Harvard Medical School, Beth-Israel-Deaconess Medical Center and received a Master of Science degree from Harvard School of Public Health. He is a practising Interventional Cardiologist, Inventor, and Educator. He founded the Journal of Cardiovascular Translational Research, has edited three books on cardiovascular translational research, and has held annual symposiums on medical product development. Dr Dib is the Founder and President of the International Society for Cardiovascular Translational Research.

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FURTHER READING AND RESOURCES

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Online Course – Translational Pathways for Cardiovascular Devices: https://isctr.org/courses/translational-pathways-for-cardiovascular-devices/
eBook – Translational Pathways for Cardiovascular Devices

A CROSS-DISCIPLINARY SUSTAINABLE CHEMISTRY SUMMER PROGRAM

To protect Earth's environment and endangered species, chemists, material scientists and engineers will need to be more mindful of the substances they produce and use. To this end, **Dr Greg Swain**, Professor of Chemistry at Michigan State University, created the Cross-Disciplinary Training Program in Sustainable Chemistry and Chemical Processes. This innovative program teaches undergraduate chemistry students the importance of sustainable practices, while preparing them for their future careers.

Reducing Harmful Chemical Products and Processes

In recent years, a growing number of scientists, institutions and companies have been trying to increase the sustainability of their practices, to protect Earth's environment and biodiversity. This includes chemists – scientists who study chemical compounds, reactions, and processes.

Sustainable chemistry, also referred to as green chemistry, is a field that promotes the development and use of chemical products and processes that are safer, cleaner, healthier, and more environmentally friendly. There are several different ways in which chemistry can be made more sustainable.

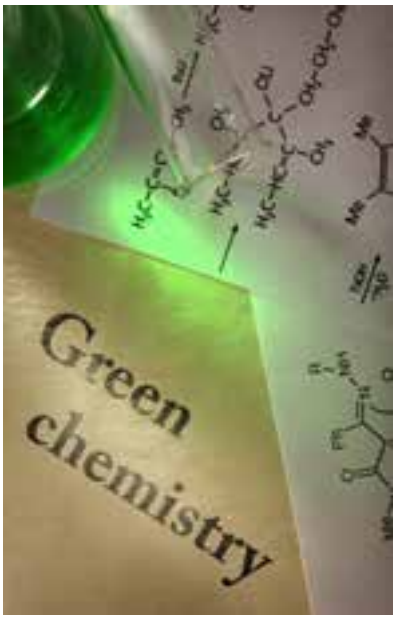
Firstly, chemists can design and identify new chemical processes that maximise the amount of raw material that ends up in a product and minimise the amount of waste produced, particularly hazardous waste.

Chemists can also design and use more substances, including solvents, which are safe and environmentally benign, with an eye towards reducing the global production and use of toxic chemicals. Finally, they can choose to use renewable energy sources and processes that are both safe and energy-efficient, to reduce energy consumption and the combustion of fossil fuels.

Combined, all these actions could pave the way towards more sustainable future, contributing to the reduction of harmful substances in the environment. Teaching future generations of chemists to be aware of how their practices impact the environment and to devise more sustainable processes is thus of vital importance, as it could contribute to the protection and preservation of our planet.

Training in Sustainable Chemistry and Chemical Processes

To best prepare undergraduate chemistry students for the professional challenges they will face in the future, Dr Swain created the Research Experience for Undergraduates (REU) site entitled Cross-Disciplinary Training in Sustainable Chemistry and Chemical Processes. The REU site was established in 2014 and continues to be funded by



the Division of Chemistry at the National Science Foundation (CHE-2150173).

The purpose the NSF's REU programs is to support undergraduate students in meaningful, graduate-level research in topical areas supported by the agency. The MSU REU site is designed to teach students about green chemistry concepts, while also fostering their professional development and offering them the opportunity to gain valuable direct research experience.

The innovative program teaches participating students how sustainability concepts can be applied across a wide range of chemistry sub-fields, including analytical, biological, inorganic, organic, and physical chemistry. During the training period, students also gain hands-on research experience and develop laboratory skills, which provide them with tangible examples of how sustainable chemistry can be applied in research and development settings.

The program has five overarching goals. The first is to involve undergraduate students in graduate-level research focusing on sustainable chemistry and engineering. The second and third are to offer them positive mentoring experiences and equip them to succeed in graduate school. Finally, the program is designed to give the students a set of tools that they can use in experimental settings, significantly enhancing their professional development. Effective mentoring is a hallmark of the program. Students also receive education in responsible and ethical conduct of research and chemical hygiene and laboratory safety.

Participating students receive a stipend and are recruited on various platforms, including the National Science Foundation's REU website, the department's website, and other recruitment pipelines. As a result, the groups of participants have so far been highly diverse, with students from different academic and cultural backgrounds.

A Hands-On and Cross-Disciplinary Program

Two of the most notable aspects of the program developed by Dr Swain are its practical and cross-disciplinary nature. In contrast with many conventional summer programs, this training course offers students the opportunity to attain real, hands-on, research experiences that apply sustainable chemistry concepts across different sub-fields of chemistry and engineering.

The program starts in mid-May and includes 10 weeks of training in a laboratory setting, as well as specialised workshops, statistics training, ethics seminars and networking events. The students are also asked to complete weekly assignments, including conducting literature searches, reading journal articles, and completing short weekly progress reports. At the end of the program, students present the results of their study at two events: a university-wide research symposium (poster presentation) and a symposium organised by the university's Chemistry Department (oral presentation).

During the 10-week laboratory training, students are taught sustainable chemistry concepts and participate in the design and execution of a research experiment. Subsequently, they also analyse and interpret the data they collect, review past research in the same area, and write up their findings in a report.

The students also attend several activities focusing on sustainable chemistry concepts, as well as some workshops on statistics, literature reviews, ethics, and lab safety protocols. To teach green chemistry, Dr Swain and the other mentors involved in the project use a series of educational videos and materials created by the American Chemical Society's Green Chemistry Institute.

The faculty members teaching and mentoring the students throughout the program have different specialties and academic backgrounds, including analytical chemistry, physical chemistry, organic and inorganic chemistry, civil and environmental engineering, materials science, and chemical engineering. As a result, the students learn about how sustainable practices can be introduced in all these different fields, providing them with a broad knowledge of green chemistry.

Networking and Professional Development

In addition to completing the 10 weeks of core training activities and working on their research projects, students participating in the Cross-Disciplinary Training Program in Sustainable Chemistry and Chemical Processes are also offered the opportunity to attend valuable networking events and professional development classes.

For instance, during their first week of training, the students attend a workshop that teaches them how to write a resume, cover letter, and personal statement. The skills they acquire during this workshop can assist them in applying for jobs and post-graduate education.

Every Wednesday, students also attend a presentation given by faculty members, as well as scientists working at General Motors and the Dow Chemical Company – a materials science company based in Michigan. During these presentations, the industrial scientists first discuss purposeful research projects and then also speak about internship opportunities at their companies, offering tips that could aid the students' professional development.

During the program, students have the opportunity to attend various networking events, including a networking picnic, student-faculty networking dinners, and Q&A sessions focusing on graduate courses, post-graduate courses, and career paths. These networking activities are organised by the Undergraduate Research Office at Michigan State University. Finally, one day of the program is dedicated to a field trip to the Dow Chemical Company, where the students can observe some of the sustainable processes implemented by Dow.

Evaluating of the Program's Impact

Dr Swain is evaluating the outcomes of the program through a series of assignments and surveys. As part of their training, all students are expected to prepare a research abstract, write weekly research progress reports, prepare oral and poster presentations for the two research symposiums, and write a personal statement. These assignments can be used to assess what the students learned during the program and provide feedback to the students on their writing style.

To better tailor the program to the students' needs, Dr Swain also asks them to complete a three-part questionnaire mid-way into the program, asking them to provide feedback on what aspects they find useful and what parts are more challenging. Their responses are discussed with mentors and used to tailor specific aspects of the program to individual students' needs.

At the end of the program, participants also complete three different exit surveys. The first includes 20 questions asking them to share their feedback about components of the program, while the second is specifically designed to compare the program's performance to that of other summer programs offered at Michigan State University. Finally, the students complete a self-assessment questionnaire, which asks them what they learned during the program.

The feedback and data that Dr Swain has collected so far is very positive and encouraging, as most participating students reported that they learned a great deal from the program. A majority of the students felt that the program was very interesting and useful, particularly the sustainable chemistry research and professional development opportunities. The program has provided them with valuable laboratory training, soft skills development and improved their overall confidence about their abilities as a researcher.

Moving Towards a Greener Future

The Cross-Disciplinary Training Program in Sustainable Chemistry and Chemical Processes is a remarkable example of how undergraduate chemistry students can be introduced to more sustainable research and development practices, while also acquiring valuable professional and academic skills. In the future, the program could inspire other universities and colleges to develop more academic chemistry courses with a focus on sustainability.

Combined, these programs could have transformative effects on existing chemical processes and practices, through the training of responsible chemists who are mindful of how their work impacts their environment. This could contribute to the reduction of environmentally harmful activities, thus supporting global efforts to tackle pollution, climate change and natural resource depletion.

'The incorporation of green chemistry principles into the research activities will equip and inspire a next-generation of chemists to solve the greatest sustainability challenges facing our planet,' says Dr Swain. 'This training will benefit society through safer laboratories and laboratory practices, reduced volume, and toxicity of chemical waste, and educating engaged and inspired students on how they can be better stewards of the environment in their research activities.'

Meet the researcher

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Dr Greg M. Swain is a Professor of Chemistry and member of the Neuroscience Program at Michigan State University (MSU). He is the former Director of the Graduate Neuroscience Program and the current Responsible and Ethical Conduct of Research Education Coordinator in MSU's Graduate School. He holds a BA in Chemistry from University of Texas at Dallas and a PhD in Analytical Chemistry from University of Kansas. Before he started working at MSU, Dr Swain was an Associate Professor and Associate Department Head in the Department of Chemistry and Biochemistry at Utah State University. In the early stages of his career, he also worked as a Reservoir Chemist and a Research Chemist in industry. Dr Swain's research group at MSU is well-known for the study of electrochemical reactions at conductive diamond and diamond-like carbon thin-film electrodes, as well as the application of these electrodes in electroanalysis, spectroelectrochemistry, neuroanalytical chemistry and biomedical diagnostic devices. Over the course of his career, Dr Swain has published over 200 scientific papers in renowned scientific journals. He also serves as Editor-in-Chief of the journal, Electroanalysis (Wiley).

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MICHIGAN STATE UNIVERSITY

TEACHING STUDENTS TO APPLY GEOGRAPHIC INFORMATION SYSTEMS TO REAL-WORLD PROBLEMS

Tools used to analyze agricultural systems, quantify natural resources, and identify sustainable agricultural processes and resource management solutions have evolved considerably in recent years. Many current tools utilize data gathered by geographic information systems, which collect and combine data from different disciplines. **Dr. Chastity Bradford**, Head of the Biology Department at Tuskegee University, has been involved in a project that introduces students to geographic information systems, teaching them how to apply such systems in multi-disciplinary research focusing on food, agriculture, health and natural resources.

Geographic Information Systems

Today, researchers working in different fields have access to a wide range of technologies and analytical tools, including machine learning algorithms, data visualization techniques, and predictive modelling methods. These innovative, advanced tools are designed to analyze pools of existing data to make reliable predictions, build visualizations and learn more about a particular topic of interest.

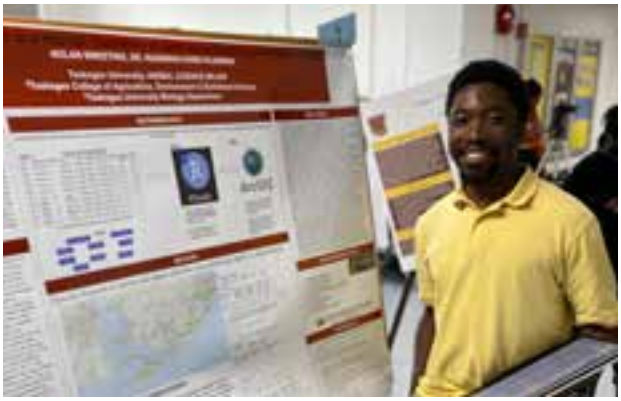
Among the fields that benefit from such technological advancements and data analysis methods are agriculture, food production, and natural resource management. In these contexts, new technologies are helping scientists to sustainably manage the natural resources available on Earth, and to improve agricultural processes so that they are less harmful to the environment.

Geographic information systems (GISs) are highly effective for conducting research focusing on agriculture, food, and natural resources. A GIS is essentially a computer system that can detect, capture, store, and display rich geographical information, such as mapping the layout of urban and natural environments. The most well-known GIS platform is arguably Google Maps, yet many other similar systems exist and are used by scientists every day.

Teaching Students How to Use GISs

The climate on Earth is changing rapidly and humanity now faces numerous challenges associated with natural disasters, food and water shortages, health risks, limited natural resources, and growing urbanization. GISs are proving to be highly valuable for tackling these challenges, as they allow scientists to better understand the spatial patterns underlying them, the geography of specific regions, and natural resources available.

As GIS platforms are now widely used in research settings worldwide, students graduating in agricultural, environmental, and human sciences could greatly benefit from knowing how to apply them to their studies. Dr. Chastity Bradford, Head of the Biology Department at Tuskegee University, has developed a program aimed at teaching students from underrepresented minority groups how GIS platforms can be used to conduct research focusing on food, agriculture, health, and natural resources.



The new program is called Discovering FACTs (Food and AgriCultural Tools), which Dr. Bradford created in collaboration with her colleague Olga Bolden-Tiller. A key objective of Discovering FACTs is to provide engaging, hands-on experiences for students at Tuskegee University, allowing them to familiarize themselves with GISs.

GISs are incorporated into every summer project proposed. Participants will be trained, certified, and eligible for a 12-month license after completion of the Discovering FACTS summer course and applied-research experience.

The GIS Training Course is led by GIS expert faculty, Dr. Souleymane Fall and Dr. John Meyers. Students learn GIS concepts, basic theoretical concepts, computer cartography, database systems, getting maps into digital form, and geocoding, while also becoming familiar with Arc-GIS software. Ultimately, by increasing the students' understanding of GISs and their possible applications in research settings, the team hopes to better prepare them for further post-graduate studies and workplace experiences.

The program is designed to improve the self-efficacy, grit, creativity, and professional resilience of STEM undergraduates or recent graduates. In addition, it aims to strengthen the students' sense of community, training them to collaborate with fellow scientists and with experts in other fields.

A 10-Week Research Program

Discovering FACTs is part of a series of projects known as Research and Extension Experiences for Undergraduates. These projects aim to create immersive experiences for undergraduate students, allowing them to take part in multi-disciplinary research studies and learn how to make the best use of modern technologies.

"Our team of investigators at Tuskegee University is composed of excellent faculty equipped and prepared to train the next generations of leaders," says Dr. Bradford. "Participants will join one of seven labs proposed to embark upon their GIS Applied-Research Experience. The Lab component of the training will allow students to use GIS software to explore, create, process, analyze spatial data and complete projects."

Some examples of student projects include "Precision Farming and Disease Management for Small-Scale Farmers", "Lemongrass-Infused Biodegradable Plastic" and "Epigenetic Modifications of G-Protein Coupled Estrogen Receptor Expression in Health".

"The goal of Discovering FACTs is to immerse students in investigation directed by a co-mentoring team comprised of energetic and productive faculty, who serve as minority science mentors," says Dr. Bradford. "To achieve this goal, we engage rising sophomores, juniors and seniors in a 10-week research and extension immersion in food, agriculture, natural resources and human sciences with GIS subthemes, with the goals of increasing the number of underrepresented individuals in this area in preparation for the workforce including positions that require a PhD."

The Discovering FACTs program offers students the opportunity to take part in 10 weeks of on-site research rooted in different disciplines, including agriculture, natural resource management, biology, and chemistry. During these 10 weeks, participants receive a stipend of $450 per week, as well as free accommodation. While conducting their studies, the students are taught how to use GIS technologies to integrate and analyze research data. In addition, they are offered the opportunity to participate in valuable career development activities.

The program targets rising juniors, seniors and outstanding sophomores majoring in different STEM subjects, with grade point averages of above 3.0. Dr. Bradford and Dr. Bolden-Tiller hope that their project will also contribute to increasing diversity in STEM fields. When advertising the program, therefore, they particularly targeted women and students at minority-serving institutions, including Fort Valley State University, Alabama State University, Florida Agricultural and Mechanical University, Prairie View A&M University, and Alabama A&M University.

Immersive Laboratory Experiences

During the first week of the 10-week program, participating students receive research-specific training, to ensure that they are equipped with the skillset necessary to conduct their multi-disciplinary experiments. In the following eight weeks,

the students spend most of their days in research laboratories, collaborating with their mentors and other students in their research groups.

Every two weeks, the students complete a progress report explaining what they achieved so far, and these reports are then signed by their mentors. The program participants are also asked to attend a one-hour application course called "Introduction to GIS" one day of every week, as well as other seminars, social events, workshops, and group discussions.

During the research process, the students learn to use GIS systems to collect and analyze data related to the geographic distribution patterns of food, farms, natural resources, health hazards, and other factors. In addition to their hands-on research projects, participating students take part in an agricultural extension initiative aimed at educating farmers, agricultural professionals, and other stakeholders about sustainable practices and the use of GIS platforms.

Extension Training

The agricultural extension component of the Discovering FACTs program builds on an existing program offered at Tuskegee University, as part of the university's Cooperative Extension Program and work by the Carver Integrative Sustainability Centre. The goal of this component is to teach undergraduates about the importance of extension initiatives, which are aimed at disseminating valuable scientific information and practices among specific communities.

In the context of the Discovering FACTs program, students engage with different extension professionals working on community development, consumer science, youth development, environmental sustainability projects, or specialized in the management of small sustainable farms, forests, ranch settings, natural resources, or food systems. They also attend luncheons to engage with Extension Agents. This allows the students to learn more about opportunities in their field of study and how they can apply their new skillset in a real-world setting.

Preparing the STEM Workforce of Tomorrow

So far, the program devised by Dr. Bradford's team has proved to be a very promising and beneficial initiative. It has allowed several undergraduates and recent graduates, many of whom are from cultural backgrounds that are underrepresented in STEM fields, to become better acquainted with GIS platforms within real and multi-disciplinary laboratory settings.

In the future, the team plans to publish the results of their ongoing project evaluation, which assesses the benefits and limitations of their program more in-depth. Their project evaluation will entail the analysis of survey and interview data collected at the beginning, during, and at the end of the 10-week research and learning experience. These interviews and surveys allow the team to collect feedback from students, mentors, and program administrators on each of the components and learning experiences in the program. They also explore the impact that these experiences had on the students' skills, development, sense of community, and confidence.

In addition, Dr. Bradford and her colleagues plan to track the progress of all students who took part in the program, to learn whether it positively affected their professional skillset and career trajectories. This will be done through social media and online, by tracking the program participants' publications, presentations given, conferences attended, and other professional achievements.

Ultimately, programs like Discovering FACTs play a crucial role in ensuring that new generations of scientists are well-equipped to join the STEM workforce and to collaborate with others to tackle the complex climate, environmental, and public health-related challenges of our times. The work by Dr. Bradford and her colleagues could thus also serve as a valuable inspiration for other educators and academics worldwide, perhaps paving the way towards the development of similar hands-on training programs.

Meet the researchers

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Dr. Chastity Bradford is Head of the Biology Department and an Associate Professor of Biology at Tuskegee University. She holds a PhD in Cellular and Molecular Physiology from University of Alabama at Birmingham and a BS in Biology from Spelman College. She was a Howard Hughes Faculty Fellow/Postdoctoral Associate in the department of Physiology and Functional Genomics at the University of Florida's College of Medicine. Dr. Bradford worked as a Visiting Professor at the Temple University Cardiovascular Research Center. She has been devising community-targeted health initiatives and academic projects aimed at increasing diversity in STEM. She focuses on discovering culture-tailored non-pharmacological intervention strategies that aid blood pressure control in rural Black Belt counties. She has trained PhD candidates, Master's students, undergraduates, and K-12 teachers. Over the course of her career, Dr. Bradford has carried out extensive research focusing on the role of the renin-angiotensin-system in cardiovascular remodeling and hypertension. She is now the Project Director of a program aimed at training students to use Geographical Information Systems to solve real-world challenges, funded by the USDA/NIFA.

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TUSKEGEE UNIVERSITY

INFUSING MAINSTREAM STEM EDUCATION WITH INDIGENOUS CULTURE, LANGUAGE AND VALUES

In the USA, approaches to Science, Technology, Engineering, and Maths (STEM) instruction are aligned with English-speaking, White middle-class norms. STEM courses rarely reflect consideration for the unique backgrounds of Indigenous learners. Because of this devaluing of local cultural, linguistic, and community traditions, whole communities are left behind, resulting in learners' exclusion from advanced educational and employment tracks. **Dr Sharon Nelson-Barber**, Director of Culture and Language in STEM Education at WestEd, aims to change this trajectory. She and her team explore the ways in which students' cultural backgrounds influence how they learn STEM subjects. Based on the team's findings, they have developed innovative STEM education and assessment methods that shift relationships between Indigenous ways of learning and Western educational practices.

Integrating Indigenous and Minoritized Cultures in STEM

Ensuring that STEM courses are compatible with the linguistic needs and unique cultural backgrounds of all students is of utmost importance to Dr Nelson-Barber. She believes that finding ways to support diverse teachers and learners to bridge worldviews will help learners realise their academic potential, while also enriching the STEM community with a broader range of perspectives.

Minoritized groups such as Indigenous populations are still widely underrepresented in scientific and engineering fields. This is largely because most STEM education courses in the US implicitly represent White, mainstream cultural perspectives, with little regard for diverse concepts and knowledge systems. Many students from minoritized backgrounds, including many Indigenous students, do not 'see' themselves or their ways of knowing represented in conventional academic curricula. Such curricula, which typically reflect cultural values and heritage that these students do not share, also effectively perpetuate the systemic inequalities that disenfranchise them.

Working with Indigenous Communities

Dr Sharon Nelson-Barber, of Rappahannock Indian and African American descent, has life-long personal and professional experience with this work. As Director of Culture and Language in STEM Education at WestEd, she has dedicated most of her career to better understanding how students' cultural backgrounds influence how they make sense of STEM subjects. Her research proposes valuable methods for incorporating diverse perspectives, values, and languages in STEM teaching and assessment practices. Common misconceptions that reduce the validity of assessment outcomes include underestimating students' English proficiency, overestimating their heritage language proficiency, and lowering academic expectations as a result.

In spite of colonisation and aggressive assimilation intended to extinguish heritage languages and identities, Indigenous communities continue to maintain knowledge systems that are coherent and complete unto themselves, including values, norms, and lifeways. As noted by Dr Nelson-Barber and her colleague Dr Zanette Johnson in 2016, when mainstream assumptions are encoded into educational norms, this poses challenges for Indigenous students, who must be the ones to bridge the gap in areas such as community values, worldview, environmental knowledge, socioeconomic status and teacher/student roles.

It is profoundly unjust that Indigenous students have had to bear the constant weight of adapting to US conventional norms in order to succeed in educational spaces. Educational researchers and instructors must now be the ones to shoulder responsibility for expanding the range of learning opportunities that are accessible to students of all backgrounds.

To better understand how students with distinct cultural backgrounds approach and relate to STEM disciplines, Dr Nelson-Barber engages with educators, elders, and other local knowledge keepers. These individuals have a deep understanding of their communities and insights about how their cultural values can be incorporated in instruction to positively impact students' learning.

'Our work highlights the need to work side by side with community members who carry the linguistic, cultural, and institutional knowledge of their communities,' says Dr Nelson-Barber. 'My team approaches this research knowing that the community members are the real experts in their domain; we each lend our unique perspectives about valued outcomes.'

Interventions for Indigenous Students

With classrooms becoming increasingly diverse, and technology and science advancing at an increasingly rapid pace, educators must turn to local excellence for assistance in adapting academic approaches that will better equip students to face future challenges. Dr Nelson-Barber and her team regularly co-develop and try out new teaching approaches side by side with Indigenous community members and educators.

Drawing upon research to design effective STEM instruction is important, but best practices identified on the basis of research with culturally 'mainstream' students may have limited utility in informing STEM instruction for Indigenous students. These so-called 'best practices' often work best for White middle class learners, since they do not consider the students' linguistic and cultural backgrounds, nor do these education methods draw on beliefs, values, or goals outside the mainstream or require family or community involvement.

Over a three-year period, Dr Nelson-Barber and Dr Johnson interviewed practicing Diné educators who were earning master's degrees and Native language teaching certifications. The researchers learned about the extent to which some 'proven' research-based STEM education methods actually limited students' academic performance because it supressed their cultural values and vitality. Diné teachers also held that involving families in their children's schooling was a beneficial approach for their students, though it does not necessarily apply to students from White majority backgrounds. This could be a reflection of lingering fallout from the colonial ways of 'educating' Indigenous people, which involved aggressive learning programmes that were intended to erase Native cultures, replacing them with those of the colonisers, as well as differences in cultural values.

The forced removal of youth from homes and communities to boarding schools interrupted the natural acquisition of language and culture for generations. Returning youth, denied their language, could no longer interact with grandparents and community elders, removing important cultural learning, and directly contributing to the erasure of cultural and community knowledge. Assimilationist practices embedded in current school reforms continue to disregard students' Native languages, cultural differences, dialectal protocols, cultural traumas, and social hierarchies.

As a result of this program, administrators have been learning about the many benefits of incorporating heritage language and local ways of knowing in everyday teaching practices. The Diné teachers described ways that they infused their instruction with 'context-adaptive' approaches. Examples include linking scientific knowledge with activities that are part of students' cultural heritage, such as sheep herding and weather prediction, or integrating local non-verbal and visual communication styles and allowing students to speak in heritage language. All of these methods contributed to improved long-term learning and knowledge consolidation.

Context-Adaptive Learning Methods

In 2016, Dr Nelson-Barber and her colleagues started adapting technology-based science learning tools in close collaboration with Indigenous educators from the Navajo Nation and Hawai'i. The educators explained the deep impact that historical trauma associated with colonisation still has on how Indigenous peoples experience formal education in public schools. 'Many of my Native colleagues talk about the heavy psychological price they paid growing up when asked to leave identity at the classroom threshold in exchange for an education,' says Dr Nelson-Barber. 'They needed to become someone else – someone who would step up to learn, and speak, and behave the "right" way.'

Over several years of research, Dr Nelson-Barber and her team identified context-adaptive methods for conducting research and teaching students in culturally diverse learning environments. One method involved adapting *FieldScope*, an online citizen science tool to support project-based learning outdoors. Teachers developed STEM instruction that reflected Indigenous cultural values, including a respect for the deep meaning of land, and incorporated an understanding of spiritual relationships among people and the land and natural resources.

Dr Nelson-Barber and her colleagues devised a new instructional aid to support the lesson adaptations: a descriptive rubric that details key aspects of teaching in Indigenous cultural contexts. The tool organises teacher knowledge around eight crucial factors for learners in Indigenous settings: contextualisation, critical self-reflection, cultural values, land-based and nature-based learning

experiences, the preservation of Native languages, family and community bonds, cognitive complexity, and authentic assessment. It delineates strategies and communication styles that are more relatable for students, since they create space for weaving with local values and traditions.

With the adaptations to the *FieldScope* platform and a new instructional model in hand, educators of Indigenous learners have a new research-based resource to help students make sense of scientific concepts in familiar and culturally relevant ways.

Culturally Appropriate Assessments

In addition to supporting teachers as they augment teaching with innovative new context-adaptive teaching approaches and resources, Dr Nelson-Barber and her colleagues have been devising more valid methods to assess STEM learning of students from Indigenous and minority backgrounds.

Through her collaborations with Indigenous educators, Dr Nelson-Barber knows the importance of recognising meaningful connections between topics covered in class and teachers' own Native heritage, ancestors, land, culture, and communities. Toward this goal of understanding how learners bridge worldviews, the work is premised on the principle that there are different cultural representations and ways of understanding science. This ultimately creates space for students to understand how they can apply what they have learned within their cultural context, and to potentially envision a career in STEM.

Dr Nelson-Barber is also developing alternative STEM testing tools that account for linguistic differences. For instance, as many existing tests have unnecessary syntactic complexity, she has been developing syntactically-straightforward tests to reliably assess middle-school and high-school students' understanding of mathematics and science concepts.

Tackling *Glocal* Challenges

The recent work carried out by Dr Nelson-Barber and her colleagues will have far-reaching implications for the academic development of students from Indigenous communities and potentially to other minoritized groups as well. In addition to identifying context-adaptive STEM teaching and assessment methods, which teachers can use to account for differences in language, culture, heritage and values, some of her projects are directly supporting students from Indigenous communities.

Dr Nelson-Barber is currently involved in studying 'science identity' development among university students in geoscience research programs focused on coastal science. This project engages learners from the US Virgin Islands, Puerto Rico, Guam, the Northern Mariana Islands, Palau, the Federated States of Micronesia, and the Marshall Islands. Over the course of five years, numerous middle-school, high-school, college level and graduate students from these islands are participating in a variety of programs by conducting authentic, original STEM research alongside university faculty. The project has supported summer camps, graduate training courses, professional development workshops, scientific conferences, and other programming all aimed at welcoming islanders to the STEM community.

This project, along with numerous other projects by Dr Nelson-Barber and her collaborators, will ultimately help to build a more diverse STEM workforce, supporting Indigenous communities as they tackle the climate crisis and future environmental challenges using approaches that centre different perspectives. Toward this goal, Dr Nelson-Barber also co-founded POLARIS (Pivotal Opportunities to Learn, Advance, and Research Indigenous Systems) – a research and development network that encourages a deep transformation in STEM education, promotes the preservation of Indigenous values and cultures, and addresses climate change and other local and global (*glocal*) scientific challenges.

Dr Nelson-Barber offers this reflection in closing: 'For millennia, the Indigenous communities we work with have been engaged in learning science, engineering, math, and technology; sustainability and knowledge of the environment are at the core of these learners' life experiences. We, as educators, are learning from *them* about how to support learners in bringing their valuable knowledge to the fore – and reshaping the discipline of "science" so that it is more diverse, accessible, and relevant. STEM has always been robustly alive in their world of everyday activity – we want Indigenous learners' knowledge to be valued, visible, and valid within the fields of STEM study and practice. And that vision begins now, with teachers crafting classroom learning that bridges knowledge systems and opens generative space for cultural identity, language and practice within school.'

Meet the researcher

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Dr Sharon Nelson-Barber has been the Director of Culture and Language in STEM Education at WestEd for the past eight years. She holds EdD and EdM degrees in Human Development from Harvard University, an MS in Disorders of Communication from University of Vermont, and a BA in Russian language and civilisation from Mount Holyoke College. Her research focuses on understanding how students' cultural backgrounds influence how they make sense of mathematics and science education. Dr Nelson-Barber has also conducted studies aimed at developing more equitable assessment and testing methods that account for cultural influences. While conducting her research, she closely collaborates with other Indigenous researchers and community partners across the US, the Northern Pacific islands of Micronesia, and parts of Polynesia. Dr Nelson-Barber is also the co-founder of POLARIS (Pivotal Opportunities to Learn, Advance and Research Indigenous Systems), a research and development network that promotes healthier communities by integrating Indigenous perspectives for thriving education futures.

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0618069: *Pacific Island Issues in STEM Education*
0529639: *Context, Culture and STEM Education in American Indian Settings*
0439605: *Native Power, Pedagogy & Place: Strengthening Education through Indigenous Knowledge and Ways of Knowing*
0352148: *Dual-Language Concurrent Assessment Development for English Language Learners*
0124047: *Assessing the Cultural Validity of Science and Mathematics Assessments*

FURTHER READING

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CULTIVATING A NEW GENERATION OF CYBERSECURITY PROFESSIONALS

Computer systems underpin nearly every aspect of modern life, but they're more vulnerable than many people realise. Threats to cybersecurity can come from anywhere in the world, at any time, and the techniques that malicious agents use are constantly evolving. As such, well-trained cybersecurity technicians are absolutely critical to our modern world, but there is a scarcity of such individuals. Now, **Dr Ahmet Mete Kök** and his colleagues have developed a new online certificate degree program at the Borough of Manhattan Community College, focused on educating and training a new cohort of cybersecurity technicians from diverse backgrounds.

The Vulnerability of the Ubiquitous

Our modern world is built upon computing. The cyberinfrastructure behind this technology is the backbone of communication, healthcare, banking, education, transport, the electrical grid, water, logistics, academic research, and just about every aspect of our daily lives. Maintaining the security of this cyberinfrastructure is therefore critical. However, cybersecurity is unlike any other kind of security, and it requires a cohort of dedicated and well-trained experts to administer.

While breaching physical security systems requires physical access, cyberinfrastructure by its nature is distributed, and attempts to breach cybersecurity can originate from anywhere in the world. While damaging or accessing physical security requires time and effort, algorithmic attacks can target thousands of cybersecurity systems at once, remotely and repeatedly. A security system is only as strong as its weakest point, and so cybersecurity requires cutting-edge knowledge to continually evolve with changing technology.

Unfortunately, the cohort of qualified individuals is small. Jim Gosler, NSA Visiting Scientist and founding director of the CIA's Clandestine Information Technology Office, highlighted the problem, saying: 'There are about 1,000 security people in the US who have the specialised security skills to operate effectively in cyberspace. We need 10,000 to 30,000.'

The Online Cybersecurity Certificate with Stackable Credentials

Dr Ahmet Mete Kök, Dr Ching-Song Wei and Dr Mohammad Q. Azhar have developed a new Online Cybersecurity Certificate program at the Borough of Manhattan Community College (BMCC), which is part of the City University of New York system (CUNY). Their project, entitled 'BMCC-ATE Project: Online

Cybersecurity Certificate with Stackable Credentials' (NSF-DUE 2100225), is designed to address the potentially calamitous shortage of cybersecurity professionals, by providing an inclusive pathway for students to gain crucial skills.

Funded by US National Science Foundation, the BMCC-ATE Project builds upon the successes of a five-year cybersecurity project that started in

2016 called 'Fostering Student Success in Cybersecurity and Information Assurance'. The new project gives participants the opportunity to acquire necessary skills that will prepare them to seek employment in the cybersecurity workforce. If they wish to further their education, the project provides participants with 30 'stackable' credits that count toward an associate degree in Computer Information Systems at the Borough of Manhattan Community College.

While the 2016 project focused exclusively on recruiting existing college students and new college students from high schools, the current BMCC-ATE Project is also open to IT workers who wish to upgrade their skills and advance their careers. The new project is more inclusive, as the course content has been adapted to be delivered online, allowing IT workers to participate in the certificate program around their work schedules. The BMCC-ATE Project is also specifically designed to support students who are typically underrepresented in STEM fields, improving their access to cybersecurity education through flexible online study and by fostering support networks.

The project started in September of 2021 and will run until August of 2024. In this time, the project will have trained at least 130 participants, preparing them to apply their new expertise to enter into the critical field of cybersecurity.

Teaching a Rapidly Evolving Subject

The challenge with cybersecurity is the constant arms race that experts face, due to emerging and rapidly evolving threats. Maintaining secure systems requires both a deep understanding of the fundamentals of cybersecurity, and an up-to-date understanding of the constantly evolving threats that are developed by malicious actors.

With their decades of combined experience in both education and cybersecurity, Dr Kök, Dr Wei and Dr Azhar are well suited for this challenge. Dr Kök has crafted curricula for Multimedia, Health Informatics, and now Cybersecurity. He also spearheaded the formation of the Virtual Cybersecurity Lab at the Borough of Manhattan Community College during lockdown, with a focus on accessibility to ensure equity and inclusion of disadvantaged students.

Dr Wei, Professor and the Chairperson of the Computer Information Systems Department at the College, serves as the Internship Coordinator of the project. his background covers both PhD research into Computer Science, and extensive experience in industry, providing a non-academic perspective on the curriculum. He has developed new courses, established articulation agreements, and has placed students in mentorships, internships, and apprenticeships to bolster their success.

Dr Azhar, Associate Professor of Computer Information Systems, joined the team as a Recruitment Coordinator, supporting the project's goal to improve access for previously underrepresented communities. During the height of the COVID-19 pandemic, Dr Azhar developed the first virtual hackathon at the Borough of Manhattan Community College, which was focused on equity and social justice. He also draws on the experience of many academic and industry projects, such as the Cybersecurity Workforce Development project funded by the NSF's Advanced Technical Education project.

The team aims to share the online curricular materials that they have developed for the certificate program with the cybersecurity community, which will contribute to a global, collaborative goal of technological education.

For such a rapidly evolving field, the team understood that it would be vital to focus on the professional development of the College's teaching staff. As such, the project includes several objectives for developing a diverse and intellectually vigorous faculty, including training instructors to deliver content online effectively and establishing a cohort of new tutors, trained specifically in cybersecurity.

Further, the team also plans to embed the Borough of Manhattan Community College and its staff in the global research community, conducting workshops as part of the Cybersecurity Professional Learning Community and presenting at international conferences.

The team established a new, state-of-the-art virtual cybersecurity laboratory for teaching the certificate courses, as well as an extra-curricular Cybersecurity Club for students to engage socially with like-minded individuals. Outreach programs were launched, such as High School Cybersecurity Awareness Workshops and Tech Talk presentations from industry partners to inspire and prepare students for careers in cybersecurity. They also established additional programs such as industry certification workshops and internships with industry partners, which will continue to provide opportunities for graduates of the new certificate program.

Improving Access for Underserved Communities

This project has a unique focus on improving the access of underserved groups to cybersecurity education. The Borough of Manhattan Community College itself is a predominantly Hispanic-serving institution, in which 75% of students are from communities that are underrepresented in the cybersecurity field, and in STEM more broadly.

This means that the project provides new opportunities to traditionally underserved communities, opening doors to high-paying and rewarding careers. In addition, the field of cybersecurity is currently constrained by a dire scarcity of well-trained professionals. As such, providing opportunities for underserved students to pursue cybersecurity careers will lead to a cohort of new talent entering the workforce at this critical time.

The team has endeavoured to make the course flexible and compatible for as many applicants as possible. The project's online delivery adds more flexibility, improving access to individuals with travel restrictions and those with family or work commitments.

To ensure that participants can complete the course during their tenure at the College, and to highlight the value of their previous work, stackable credentials such as industry certifications and prior experiences are mapped to credit-bearing college courses.

The certificate program's curriculum consists of 30 college course credits, broken down into 10 individual courses. Participants who complete the program will have the flexibility to enter the workforce directly, or to further their education and specialisation by earning advanced credentials such as a college degree.

The certificate program also includes enrichment activities. Younger participants can enrol in an online course called the 'Summer Bridge Course Program', which offers free tuition and deliberately small classes for more individualised teaching. At the end of the summer, the participants who complete this program will earn credit for a computer science course, which is transferable as an elective in any college within the City University of New York system, or towards the Cybersecurity certificate itself.

Those who are participating in the BMCC-ATE Project also have access to a variety of virtual internships – a relatively new concept that has erupted in popularity since the start of lockdown. Universities across the world are adapting traditional internships for an online delivery system, dramatically reducing the costs that hinder many disadvantaged students. Last summer, the New York financial company Bank of New York Mellon mentored 85 virtual interns. These mentorships coupled with internships introduce students to valuable contacts within the industry and build collaborations between academic and industrial communities.

The Online Cybersecurity Certificate program developed by Dr Kök, Dr Wei and Dr Azhar will undoubtedly advance the field of cybersecurity, building a new and diverse generation of experts who are well-equipped to protect the critical systems underpinning our modern world.

To find out more information about the project please visit http://cis.bmcc.cuny.edu/cybersecurity.

Meet the researchers

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Dr Ahmet Mete Kök received his PhD in Computer Science from the City University of New York Graduate Center in 1994. He is now a Professor in the Computer Information System Department at Borough of Manhattan Community College in New York City. He currently serves as the Principal Investigator of the National Science Foundation's Advanced Technological Education (NSF-ATE) program and the Department of Education Hispanic Serving Institute (HSI-STEM) Articulation funded projects in Cybersecurity articulation and workforce development. Recently, Dr Kok spearheaded the formation of the Virtual Cybersecurity Lab at BMCC during the COVID-19 pandemic. The accessibility of this resource ensured the equity and inclusion of disadvantaged students and promoted student success in cybersecurity. His research interests include computer networking; network modelling and performance evaluation; computer network security and resilience.

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Dr Ching-Song (Don) Wei is a Professor and the Chairperson of the Computer Information Systems (CIS) Department at Borough of Manhattan Community College. He received his Master's in Mechanical/Manufacturing Systems and PhD in Computer Science. As the Chairperson of the CIS Department, Dr Wei has been actively involved in developing new curricula; establishing articulation agreements; and placing students in mentorship, internship, and apprenticeships. He has served as Principal Investigator and Co-PI for numerous projects including the NSF-ATE, HSI-STEM programs in the areas of cybersecurity, geospatial technology, and mobile programming. Dr Wei serves as a co-PI for the Cybersecurity Workforce Development project and was instrumental in institutionalising the Virtual Cybersecurity Lab. Dr Wei has authored and published articles in the areas of Clinical Information systems, Machine Learning, Data Engineering, and Semantic Web Services.

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Dr Mohammad Q. Azhar received his PhD in Computer Science from the Graduate Center, The City University of New York (CUNY), in 2015. He is now an Associate Professor of Computer Information Systems at Borough of Manhattan Community College (BMCC). As the faculty advisor of the BMCC Computer Programming Club and ACM-W chapter, he engages students in leadership and co-curricular learning. His research and projects include numerous NSF, DOE, CUNY and Industry projects. Dr Azhar is a co-PI for the NSF-ATE Cybersecurity Workforce Development and HSI-STEM Articulation programs. He was instrumental in the establishment of BMCC's Virtual Cybersecurity Lab. His current research interests include Human-Robot Collaboration, Artificial Intelligence and Assistive Robotics, Computer Science Education and Cyber Security.

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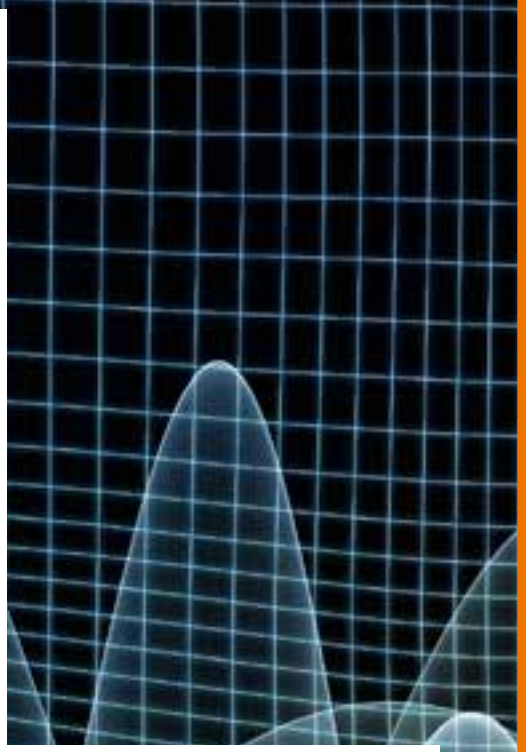
PSYCHOLOGY & NEUROSCIENCE

AN EXCITING NEW PERSPECTIVE ON THE *HOW* AND *WHY* OF CONSCIOUSNESS

Consciousness is a vast and complex topic. **Dr Birgitta Dresp-Langley**, Research Director at the Centre National de la Recherche Scientifique (CNRS) in France, takes a revolutionary and exciting new perspective in her reasoning on how consciousness came to be and how we can harness its power for a better world.



Defining Consciousness

A specific and consensual definition of consciousness continues to elude scientists. Very broadly defined, consciousness can be considered to be a mental state that one is aware of being in. Field theories have been influential in the study of consciousness and depend upon objectively measurable interactions in space and time. In other words, they seek to examine patterns of interaction between an individual and the total field – their environment. While these theories can account for specific aspects of brain-behaviour function (such as memories, decisions and actions), they do not encompass the entirety or the complexity of conscious experience – and certainly not why or how it came to be in the first place.

The so-called 'hard problem of consciousness' refers to the difficulty in finding brain measures of the complex phenomenon we want to study, such as the 'self' and experiences of 'I am', 'I feel' and 'I will be'. We can study cognitive processes such as conscious perception, memory, decision-making and behaviour, and determine where in the brain these take place, but consciousness itself is a different matter. Phenomenal experiences, such as specific instances of perception (think of tasting a strong coffee and holding the hot mug in your hands on a cold day) occur across multiple regions and networks in the brain. But where does consciousness itself reside? And how did it come to be?

The Construction of Consciousness in Time

Dr Birgitta Dresp-Langley, Research Director at the Centre National de la Recherche Scientifique (CNRS) in France, is working to overcome the limitations of existing theories and address many unanswered questions about the *how* and *why* of consciousness.

In 2009, Dr Dresp-Langley and nuclear physicist, Dr Jean Durup, borrowed from the field of physics to propose that we have a biophysical brain code that works independently of cognitive processes such as perception and decision-making. They suggested that the brain code provides a generic mechanism that serves to trigger, maintain and terminate individual conscious states.

The researchers were interested in developing a computational account that held true to the idea that consciousness reflects a specific state of being in time but does not depend upon physical (spatial) location. The absence of an observable spatial dimensionality to consciousness is critical to Dr Dresp-Langley's approach and she points to how readily we can recollect the past and mentally simulate future events that haven't (and might never) happen. For example, most of us could cast our minds back to a particularly happy birthday or perhaps a difficult relationship breakdown with ease. Likewise, we can probably readily imagine what it might be like to win the lottery (even though the chances of this happening in real life are extremely slim).

She argues that this active construction of consciousness in time is fundamental to much of our conscious human life. Indeed, early in childhood, we learn much about the temporal order of the physical world long before we become aware of higher-order concepts such as the self. For centuries, philosophers have proposed that consciousness represents our recognition that we exist in, and are part of, moments in time. In an extension of this, it has further been argued that human consciousness may have progressively evolved from the primitive ability to be aware of, to remember, and to predict temporal order and change in our environment.

Dr Dresp-Langley takes the perspective that consciousness, while associated with these cognitive processes, transcends them, noting, 'By changing and developing with experience, in interaction with other beings, society, and the physical world, it [consciousness] creates potential for mobilizing new resources beyond currently existing or known physical boundaries.

Conscious Energy

Consciousness drives human creativity and the technological and cultural development of human societies as we know them. As such, Dr Dresp-Langley argues, consciousness may be seen as a form of energy – one that can lead to observable changes in ourselves, others and our physical environments. This means that consciousness also has the power to change and/or determine the future mental states of ourselves and others, and also change and/or determine future physical environments.

The origin of conscious energy is within the brain and the potential is boundless. Conscious energy underpins human creativity, the driving force of the advancement of society most broadly as we have noted. Yet there is much that still yet to be explored and our understanding of the individual and collective power of consciousness is still very limited. This is a particular interest for Dr Dresp-Langley.

Expanding Levels of Consciousness for a Better Life

Given the role of consciousness as a vital energy source, Dr Dresp-Langley points to the relevance of techniques that expand consciousness, such as meditation and mindfulness practice. She proposes that these approaches could allow us to adjust our individual expectations, and find greater purpose and fulfilment in our lives, despite any adversity that we may encounter. In this way, the energy of consciousness could be harnessed to become a fundamental driving force in achieving a better life across the lifespan.

Dr Dresp-Langley's profound work brings us to the notion that our conscious minds are not confined to what we can objectively measure, and thus, this approach is limited. Instead, she argues that we should focus our efforts on furthering our understanding of how we can expand our consciousness to improve health and well-being on individual and societal levels. Perhaps her most radical yet intriguing suggestion is that consciousness may have evolved to enable us to plan for both our survival and our extinction. We look forward to her further work on this exciting perspective.

Meet the researcher

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Dr Birgitta Dresp-Langley is a Research Director at the Centre National de la Recherche Scientifique (CNRS) in France. She obtained her PhD in Cognitive Psychology at Paris Descartes University and joined the CNRS in 1993. Dr Dresp-Langley has authored more than 100 articles in peer-reviewed multidisciplinary scientific journals, several book chapters, and is an independent scientific expert to the European Commission. She also sits on the Editorial Board of several international scientific journals published by Elsevier, Frontiers and MDPI. She has extensive expertise in the fields of brain-behaviour function, perception and cognition, human intelligence, and artificial intelligence.

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EXPLORING THE DARK SIDE OF MORALITY

Social and moral values can inspire change and positive action, yet they can also prompt divisions in society, conflicts and violence. **Dr Jean Decety**, a Professor at the University of Chicago, recently started investigating the mental and neural mechanisms associated with strong moral convictions and the support for violent acts. His work examines the dark side of morality, pinpointing the brain processes underlying moralisation and its adverse consequences.

How Social and Moral Values Guide Human Behaviour

Social values and moral norms play a crucial role in human societies, outlining how humans should behave and cooperate with others. Social values are the standards that shape the social order in a group or society, while also delineating behaviours that are deemed acceptable and unacceptable. These social values can then be 'moralised' – or in other words, become moral norms that humans internalise and view as part of their own identity.

While moral norms are typically meant to limit conflicts and promote social cooperation (for instance, suggesting that humans should not intentionally harm others), they sometimes paradoxically fuel aggressive behaviours and divisiveness. In today's highly polarised world, many violent acts are motivated by moral values and by beliefs about what is 'right' or 'wrong'. We have recently seen how activists campaigning about climate change, racism, gender identity or economic inequality, for example, can become intolerant and violent. And it is certainly the case that extremist beliefs, ideologies, and attitudes exist on both the left and right of the political spectrum.

Wars, genocides, armed conflicts, honour killings and violent protests – these are only a few examples of how rigid moral convictions can result in the tragic loss of life. Often, the violent parties behind these acts believe that they are fighting for the 'right reasons' – guided by honourable social values despite the catastrophic effects of their actions.

Dr Jean Decety at the University of Chicago has been progressing our understanding of the mental and neural mechanisms underlying morally guided violence and conflict. His work pinpoints some of the processes that may underly the increasingly polarised views of Western societies, currently reflected in political conflicts, opinionated popular media articles, and heated social media interactions on topics such as gender dysphoria, stem cell research, diversity and immigration.

Moralisation, Cognitive Flexibility and Social Influence

Dr Decety has explored several processes through which humans integrate social values and moral norms. These crucial processes include moralisation, cognitive flexibility and social influence.

Jean Decety scanning at the MRI Center, University of Chicago

Moralisation occurs when people start representing individual preferences or neutral attitudes as moral values. Through the process of moralisation, beliefs and attitudes that were previously considered morally neutral acquire moral qualities. For instance, a person might strongly believe that abortion is fundamentally wrong and thus be morally opposed to it.

Moralisation leads to the development of moral convictions, which are strict beliefs about what is 'right' and what is 'wrong'. These unshakable beliefs can potentially relate to anything – veganism, abortion, immigration, capital punishment – and countless other diverse aspects of life. Beliefs held with moral conviction differ from strong opinions, in that they tend to be so rigid that they are viewed as universally and objectively true, oppositional in nature, and can even be used to justify violent acts.

Another focus that Dr Decety has explored is cognitive flexibility – the ability to switch between different 'modes' of thinking. This means recognising the difference between *opinions* (regardless of how strong they are) and *facts*, and accepting that the concepts of 'right' and 'wrong' can be subjective.

Cognitive flexibility also includes what is known as 'metacognitive sensitivity' – a person's ability to accurately monitor and evaluate their own thinking processes, and also to adjust their behaviours and beliefs accordingly. Past studies have found that people with lower cognitive flexibility are more easily influenced by thinking biases and are also more likely to hold extreme political beliefs and support violent acts.

Dr Decety also has examined how social influence affects moralisation. Social influence is the process through which individuals align their preferences and behaviours by observing others in their community. This could mean, for instance, conforming to the beliefs of others or changing one's opinion about something after discussing it with someone else.

Moral Conviction Overrides Aversion to Violence

In a recent study, Dr Decety explored the psychological and neural mechanisms underpinning moral convictions and support for violence. Participants holding liberal political views were asked to complete a questionnaire in which they stated their moral convictions regarding socio-political issues, half of which were more liberal and the other half more conservative. These issues included abortion rights, the detention of migrant children, the Black Lives Matter campaign, climate change legislation, gun control, and several other contemporary hot and widely debated topics.

After they had expressed their moral convictions, the participants underwent functional magnetic resonance imaging (fMRI), an imaging technique that measures changes in blood oxygenation associated with brain activity. During scanning, they were shown images of violent political protests that were either aligned or in contradiction with the views they expressed in the questionnaire, and asked to rate their appropriateness and support.

Analysis of the fMRI signals and the views expressed by participants allowed the researchers to determine what happened in the brain when violent images were congruent or incongruent with an individual's beliefs. Notably, different activity patterns were observed in the ventromedial prefrontal cortex, ventral striatum and amygdala – three brain regions previously linked to moral norms and valuation processing. These patterns varied based on whether participants were presented with images that were congruent or incongruent with their moral convictions. Thus, moral conviction about socio-political issues serves to increase their subjective value, overriding our natural aversion to interpersonal harm.

Moralisation Alters Sensitivity to Social Influence

In a follow-up study, Dr Decety examined how moral conviction and cognitive flexibility influence the mental processing of information during social decision-making. Participants completed a survey measuring their attitudes on socio-political issues, a perceptual confidence task to assess their metacognition. Then their neural activity was recorded using electroencephalography (EEG) while participants evaluated images of protests advocating for the same social issues they had just been asked about. But immediately before they were shown the images, they were given statistical information regarding the opinions of their peers on the same issues they rated before and asked if they confirmed their previous responses.

Dr Decety observed that people with strong moral convictions were less likely to change their responses after learning that the majority of their peers held opposing views, reflecting a lower metacognitive sensitivity. In addition, he found that while mentally processing images related to issues that they had a moral conviction about, the participants' brain activity patterns reflected increased attention, emotion and greater engagement.

A Neurocognitive Perspective on Moral Conviction

Dr Decety's cognitive neuroscience research offers valuable insights into the mental and neural processes that underlie moral convictions and connection to violence. Given the polarised and intense social dynamics that we see across the globe about many issues – from climate change to gender identity, all hugely amplified by social media – this work has particular importance and relevance for progressing efforts aiming to reduce intransigent dogmatism and encouraging reasoning and productive dialogue. As moralisation has the potential to both inspire activism and change and also instigate divisiveness and great harm, it is important to understand the emotions, motivations and social factors that underlie and predict moralised opinions. Clearly, morality can both bind and blind us.

Meet the researcher

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Dr Jean Decety is a Professor at the University of Chicago and Director of the Social Cognitive Neuroscience Laboratory. He holds a PhD in Neuroscience-Medicine, an MSc in Biological and Medical Engineering, and an MSc in Neurobiology from the University Claude Bernard (Lyon, France), as well as a Master of Arts and Science in Cognitive Psychology and a BA in Neuropsychology and Psychopathology from the University Lumière. Dr Decety has worked at the University of Chicago for almost two decades. Before that, he was the Head of the Social Cognitive Neuroscience Laboratory at the University of Washington and the Director of Research and Head of Neurophysiology of Intentionality at the INSERM in Lyon, France. His work spans a wide range of research areas, including affective neuroscience, behaviour economics, developmental and social neuroscience, and clinical neuroscience. He is particularly interested in uncovering the neural underpinnings of social decision-making, empathy, morality, prosocial behaviour, and social preferences. Dr Decety has written countless empirical and theoretical papers and has presented his work at conferences worldwide. Over his career, he has received many honours and awards, including the 22nd Jean-Louis Signoret Neuropsychology Prize of the Foundation Ipsen in Paris. Dr Decety was elected as a member of Academia Europaea – pan-European Academy of Humanities, Letters, Law, and Sciences, in 2022.

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STEPPING INTO THE FUTURE: ENHANCING INTERACTIONS BETWEEN HUMANS AND MACHINES

Dr Michael Richardson and **Dr Rachel Kallen** from Macquarie University in Sydney have demonstrated through a wide body of research, that machines can play a vital role in collaborating with humans on perceptual-motor tasks. A key focus of Dr Richardson and Dr Kallen's cutting-edge research is enhancing the performance of artificial agents using dynamic motor primitives, to create more natural and effective interactions with humans.

Over the last few decades, technology has become an integral part of our lives. Whilst society has largely embraced this leap, there is still some reticence in the acceptance that machines can perform on an equal level to humans or even replace them in undertaking certain tasks. Dr Michael Richardson and Dr Rachel Kallen from the School of Psychological Sciences at Macquarie University in Sydney, Australia, have undertaken a wealth of research exploring how machines can be developed to interact naturally and effectively with humans.

Due to the social nature of the society that we live in, our human behaviours often involve coordinating our actions with others, especially if we have a shared goal. Working with others is more efficient and depends upon our fundamental skills in social perception. Typically, such activities involve us collaborating with other humans. However, Dr Richardson and Dr Kallen are interested in whether artificial agents or machines may be able to play a role in this context, especially given the rapid pace of development in virtual reality and robotic technologies.

They believe that artificial agents could help provide perceptual motor training and rehabilitation to humans, as well as assist the elderly or people with disabilities.

The researchers acknowledge that for artificial agents to be accepted within society, they need to have real-time coordination and the ability to respond in a way that is 'human-like'. To develop this level of performance, the detailed study and modelling of real human actions is required. Much of Dr Richardson and Dr Kallen's research has focused on testing the effectiveness of dynamic motor primitives, a mathematical formulation of human perceptual-motor behaviour, for controlling the movements and actions of artificial agents. This type of modelling can capture the two main types of motor movement exhibited by humans, which are discrete movements such as reaching or throwing and rhythmic movements such as waving and walking.

Exploring Effective Human-machine Interaction

To assess the effectiveness of artificial agents in collaborative tasks, Dr Richardson and Dr Kallen undertook a study comparing the performance of both human-to-human and human-to-machine pairings. The experimental task involved the pairs working together to herd a small flock of virtual sheep to a specific location. The results revealed that the human and machine performance was the same as for the human-to-human pairings. Importantly, Dr Richardson and Dr Kallen were able to demonstrate that complex human movement and social behaviours can be successfully modelled and implemented by artificial agents, especially when multiple parties are required to work together.

This research is supported by a further study by Dr Richardson and Dr Kallen, which aimed to assess whether artificial agents could naturally undertake 'pick and place' activities. These are the kind of actions we undertake daily with those in our households, such as setting the table or loading the dishwasher. The research found that dynamic motor primitives were successful in instructing artificial agents when to pass or not pass an object, as well as which hand movements to make. Another aim of this study was to determine whether humans were able to detect the involvement of a machine in this task. The experimental set-up involved participants wearing virtual reality headsets which masked whether their partner was another human or a machine. They were instructed to work together to move coloured discs from one area of the table to a corresponding target. The results found that at the end of the task the participants were unable to tell if they had been working with a human or a machine. This further supports the researchers' optimism about the successful involvement of artificial agents within joint human activities.

Enhancing Machine Interactions Based on Human Behaviour

Despite undertaking research which demonstrates successful partnering between humans and artificial agents, Dr Richardson and Dr Kallen have been keen to further explore how these relationships can be further enhanced. Whilst it is important for the behaviour of artificial agents to be perceived as natural by their human partners, it is also vital that machines can cope with the less predictable and more chaotic behaviours displayed by humans. For the interaction to be successful, both humans and machines need to be highly flexible and adaptive. Dr Richardson and Dr Kallen acknowledge that if machines are to play a key role in training, rehabilitation and assistance, then this is a possible barrier that needs to be overcome.

Recently, the researchers have undertaken a study investigating if improvements can be made in how artificial agents deal with chaos. They tested a theory used in cognitive science and psychology that is based on feedback delays in the human perceptual motor system. It was previously thought that processing delays may negatively affect human interactions. But more recently, research has shown very small feedback delays, of a few milliseconds, might help humans to synchronise with and anticipate the actions of another person, even if they are chaotic.

This phenomenon is referred to as 'anticipatory synchronisation' and has been applied to human-machine learning by Dr Richardson and Dr Kallen. They found that these micro delays had a positive effect and enhanced machines' ability to respond to chaotic behaviour. Interestingly, it also enabled the artificial agent to better synchronise their

behaviour with humans – this is something that typically only occurs in human-to-human interactions. This demonstrates that principles of our human behaviour can enhance the behaviour of machines, an ethos that is present throughout Dr Richardson and Dr Kallen's research. They believe the most effective approach is to combine human-inspired strategies and expertise with the more standard computer learning.

Use of Machines in Training

Another key focus of Dr Richardson and Dr Kallen's research has been the application of artificial agents in training humans, particularly in relation to motor behaviours. Most complex tasks require training for new employees, which often proves to be costly and time-consuming for the organisations involved. Involving machines in this training could be a way to increase efficiency and reduce costs. Interactive artificial agents could take on the training roles typically occupied by humans. However, to be successful artificial agent trainers would need to exhibit natural human behaviour throughout their interactions with trainees.

It has been demonstrated in Dr Richardson and Dr Kallen's research that the performance of machines can be indistinguishable from that of a human. The use of dynamic motor primitives in the modelling of artificial agents' behaviours has been heralded as a key factor in generating a high level of performance, a key issue that the researchers have gone on to test within the context of training.

Dr Richardson and Dr Kallen's research into artificial agent training used another virtual sheep herding task. This time, three different experimental scenarios were employed to assess if machines were able to provide a comparable level of training to human experts. The first and second scenarios explored the performance of human-to-human and human-to-machine pairings, respectively, and the third scenario assessed whether humans could learn successful behaviour from a model-controlled artificial agent. The researchers then measured if the humans were able to transfer these skills to improve their future performance when paired with another human.

The results demonstrated that humans could learn successfully from a machine and were also able to use this to enhance future performances with other human team members. Whilst successful, Dr Richardson and Dr Kallen wanted to establish which type of artificial agent modelling produced the most effective and human-like training performance. To assess if dynamic motor primitives were the most optimum programming principles for artificial trainers, the researchers conducted a further study comparing this with an alternative method called deep reinforcement learning. This alternative approach involves the artificial agent learning how to behave in a specific environment, through trial and error, by performing actions and seeing the results. When comparing this method of modelling through further virtual sheep herding tasks, it was clear that dynamic motor primitive modelling produces the most successful results. Further research has shown that a hybrid of both methods may be the optimum approach.

Dr Richardson and Dr Kallen have demonstrated the critical role that artificial agents can play in the training of motor perception skills across a range of industries including health and sports. Over time, machines will be able to play an increasing role in helping to improve our collaborative behaviours, and have many benefits to offer society. The researchers maintain that there is also much for humans to learn from machines. However, before artificial agents are more widely embraced in our society, greater trust and acceptance are needed from humans. Dr Richardson and Dr Kallen argue that once humans are engaged in working alongside machines as equals, then their true benefits can be realised.

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Dr Michael J. Richardson is a Professor in the School of Psychological Sciences at Macquarie University. He is the Director of the Center for Elite Performance, Expertise and Training and an Australian Research Council Future Fellow. His research is directed towards modelling the dynamics of human perception, action, and cognition and the development of human-machine interaction and AI-based training systems. He has expertise in cognitive science, human factors, complex systems, perception-action, social and multiagent coordination, AI, machine- and deep-learning, simulation and virtual reality, data analytics, and computation and dynamical modelling.

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Dr Rachel W. Kallen is an Associate Professor in the School of Psychological Sciences at Macquarie University. Her research utilises a framework of complex systems to investigate a range of social behaviours, including how the behavioural dynamics of everyday social and multiagent behaviour emerge from nonlinear interactions of the physical, informational, and social properties of agent-environment systems. Bridging both basic and applied science, her work highlights expertise in areas of social psychology (i.e., stigma, intergroup relations, social cognition), cognitive science, dynamical and computational modelling and analysis, virtual reality, human-machine interaction, AI and machine learning.

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MACQUARIE University

CHANGING THE BRAIN THROUGH LEARNING

Attention allows us to plan and monitor our thoughts and, thus, is a critical step in the learning process. Learning can then change the physical structure of the brain. This is the reason why a team of scientists at the University of Oregon, led by **Drs Michael Posner** and **Cristopher Niell**, are exploring the effects of attention on learning and how learning changes the brain.

Learning: What, Why, How?

To learn means to acquire specific skills, knowledge and understanding through study or experience. In humans, scientists can measure the quality and success of our learning by looking at different variables like speed or the number of errors on tests specifically designed to measure this aspect of our cognitive function. Typically, learning can be determined through a reduction in the number of errors made and/or completing a task more quickly.

This experimental approach allows scientists to closely examine the factors that can contribute to learning. These factors include effort, prior experience and learning strategies. However, when we think about learning at the mechanistic level in the brain, the involvement of different brain regions in the cascade of the learning process is the primary focus. Dr Michael Posner of the University of Oregon has dedicated his career to advancing our understanding of how attention is organised in the human brain and its vitally important functions. The work we discuss here is the fruit of a collaborative effort between Dr Posner and his esteemed colleagues, all of whom are working towards the common goal of advancing cognitive neuroscience.

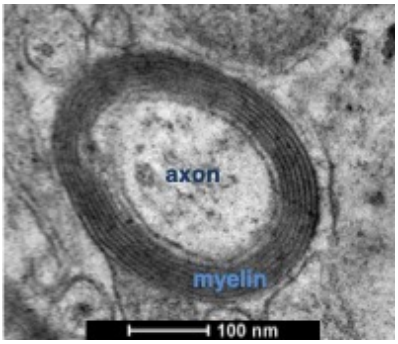
In a study published in 2019, Dr Aldis Weible (the lead author) and colleagues explored the mechanisms of learning in mice. The team focused on three critical brain regions – the anterior cingulate cortex, hippocampus and visual cortex. The anterior cingulate cortex is involved in attentional control. The primary role of the hippocampus is memory and learning regulation. Both structures are located deep in the brain's subcortical regions. The visual cortex receives and processes visual information from our eyes and processes this with the aid of attention and other brain areas. The process of learning involves all three of these brain areas (and others) that, together, form a very complex network.

This study filled some key gaps in our understanding of learning. The team discovered that each region contributes to the complex network of learning. However, they also found that this contribution fits better with a parallel rather than a serial model. To explain this, they used a racehorse analogy, whereby the brain regions work together at the same time. The anterior cingulate cortex and the visual cortex were found to be important at all stages of learning, while the hippocampus influenced mainly the middle and late stages. However, there were also differences in how these brain regions were involved. For example, the anterior cingulate cortex was linked to accuracy performance but not speed.

These findings were surprising because many previous studies had linked attention to reduced learning speed. From this novel result, it was clear that more answers could be uncovered by exploring further the connections between the anterior cingulate cortex and other brain areas.

Bringing All the Evidence Together

In one of his most recent pieces of work, Dr Cristopher Niell and colleagues collaborated with Drs Posner and Rothbart to review the scientific evidence on learning. Their combined expertise spanning neuroscience, psychology and biology allowed them to ask questions about similarities and differences between animals and humans when it comes to learning new skills. They already knew what brain regions appeared to be important in the learning process, but there was a lot more they needed to unravel about the



An electron microscope picture of a single axon (fibre that leads to another cell) surrounded by myelin rings (insulating the axon).Electron microscopy by Dr Denise Piscopo

role of attention and memory networks. Are there any special connections involved? Do they look similar in mice and in humans? And intriguingly, if we find out more about these pathways and the mechanisms behind them, could we manipulate them to improve learning?

The team was able to provide answers to several of these questions. Notably, they found that the evidence pointed towards the presence of two pathways in the brains of both animals and humans, serving to connect attentional networks with the hippocampus. The first pathway (anterior pathway) involves the brain structure nearer the front of the brain and includes the anterior cingulate cortex. The second pathway (posterior pathway) involves the brain structures further back, including areas of the parietal lobe.

Because these pathways use different routes crossing many brain structures, the team speculated about the mechanisms that might underpin learning. Most specifically, they were interested in whether the anterior pathway could be significant for generalisation – a process that helps the brain demonstrate learning in situations different from the original learning. They further proposed that the posterior pathway might be complementary to this and may play a part in navigation in the rodent and retrieval of memories related to location in the human.

Manipulating Pathways Through Neuromodulation

Neuromodulation is a technique through which we can actively change the brain's nerve activity using mild electrical stimulation or drugs. Based on encouraging results from the field of epilepsy, where neuromodulation can reduce seizures, researchers were encouraged to study its potential application to other disorders, as well as the understanding of healthy brain processes.

For Dr Posner, neuromodulation presented a very promising candidate for improving learning outcomes. Based on his earlier research, he was eager to explore the anterior cingulate cortex and surrounding brain structures, particularly in relation to improving learning. To look at this directly, the team used lasers to manipulate neuronal activity in mice in the anterior cingulate cortex.

Neuromodulation Can Repair the Brain

Neuromodulation of the anterior cingulate cortex of mice by low-frequency stimulation resulted in several exciting results. First, they showed that the brain structure close to the stimulation became more strongly connected after neuromodulation. White matter is the tissue that allows communication from one part of the brain to another. Dr Denise Piscopo (lead author), was able to take pictures magnified 16,000 times to show an increase in the white matter surrounding the anterior cingulate, allowing information to travel more quickly and more effectively to and from this structure (see Figure 2).

This was excellent news – not least because neuromodulation might help to repair the protective sheet of white matter across many different neurological problems. For example, people who suffer from concussions or multiple sclerosis have damage to white matter in diverse brain regions. These findings suggest a possible way forward to help the recovery of patients with such neurological problems.

Neuromodulation and Meditation

Plenty of evidence supports the positive effects of meditation on the brain. Some work by Drs Posner and Rothbart in conjunction with Dr Yiyuan Tang has shown that brain connections strengthened after two to four weeks of meditation training. Could meditation have similar positive effects on the brain as neuromodulation? They identified several common patterns in the literature pointing to the role of the anterior cingulate cortex, stronger white matter, and better learning outcomes on different tests and tasks using meditation training in humans and stimulation in animals.

Neuromodulation and meditation seem to involve a specific brain rhythm that causes a cascade of molecular changes in the brain. Dr Pascale Voelker is investigating these molecular changes. Taken together, both neuromodulation and mental activity, such as meditation, are believed to improve information transportation by strengthening white matter connections. This impacts real-life behavioural outcomes, such as improving concentration and emotional regulation. But how?

Next Steps in Understanding Learning

Having ascertained that neuromodulation can improve connections between structures, it is important to understand the mechanisms underlying the impact neuromodulation has on the two pathways involved in learning skills. One question is how to separate the direction of information flow in the two pathways. Understanding the direction of information flow will help determine the exact function of each pathway between attention and memory. Neuromodulation could then be targeted to help understand the function of each pathway. Hopefully, modulation can then be used to improve specific learning skills. In the long run, improved knowledge could repair white matter and thus help people to recover from neurological problems.

But, of course, very little is ever straightforward. As Dr Posner explains, 'The ability to determine the direction of information flow is critical to the design of new studies. It is hard to distinguish between memory-to-attention and attention-to-memory control in subcortical areas. Optogenetics using laser light can help them to accomplish some of these goals. By injecting the brains of mice with two different types of viruses, they will be able to separate the direction of two pathways. It is then possible to use laser light to stimulate these areas in a specific direction through surgically implanted optic fibres.

Future research could involve designing tasks for mice that would help in modulating each pathway separately. This experimental plan is similar to the researchers' previous studies looking at the contribution of different brain areas to learning. This will allow study of the specific roles these pathways have and how the information flows within them. Looking even further ahead, if successful, it may then be possible to apply similar non-invasive methods, such as stimulation from electrodes on the scalp of humans, to improve both neurological conditions and skill learning.

Professor Cristopher Niell

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Meet the researchers

Team profile

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This team began its collaboration in 2015 when after a lecture by Dr Posner, Dr Niell came forward to say that he could provide a test of Dr Posner's hypothesis that meditation could change through a frontal rhythm that might activate dormant cells. Dr Niell was using optogenetics to activate cells in the brain of mice. In addition to Dr Posner, who has studied the mechanisms of attention for more than 50 years, the team included Dr Mary K. Rothbart, a world-leading developmental psychologist with whom Dr Posner has worked for many years. Dr Denise Piscopo (working with Dr Niell) was instrumental in testing the hypothesis and developed the needed skill with electron microscopes to examine the change in white matter. Dr Aldis Weible worked with Dr Niell to train and test the mice, for which he received special recognition with a research award from the University. Dr Pacale Voelker, trained in molecular biology, added the molecular analysis to the team's work. The experiments reported in this article reflect a genuine collaboration and also build on the work of many other people in this field.

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UNIVERSITY OF OREGON

THE HALSTEAD CATEGORY TEST: ASSESSING THE IMPACT OF PRENATAL ALCOHOL EXPOSURE

Children who have been exposed to alcohol while still in the womb often show impairment in executive function – the cognitive domain underpinning diverse skills including attention, memory, learning and self-control. Psychologist **Dr David Sperbeck**, PhD, has investigated whether a commonly used neuropsychological assessment – the Halstead Category Test – can effectively measure cognitive impairment in this vulnerable group of children. His findings confirm the utility of the measure and also offer important hope for children affected by alcohol prenatally.

Prenatal Alcohol Exposure

When babies are exposed to alcohol prenatally, this can have a significant impact on their brain development, leading to impaired learning, memory, language and social skills. These deficits may lead to the diagnosis of a condition known as Foetal Alcohol Spectrum Disorder (FASD), which can negatively affect children's social adjustment and impair their readiness for school. FASD is a global concern, found in over 1% of children across 76 different countries. This highlights the need for reliable assessment protocols, preventative measures, and initiatives with the potential for universal application.

Whilst prenatal alcohol exposure has been found to cause sensory and behavioural disorders, little is known about how these disorders develop over time. Dr David Sperbeck, former Clinical Professor of Psychiatry and Behavioural Sciences at the University of Washington School of Medicine, is working to improve the clinical assessment and identification of cognitive impairment caused by prenatal alcohol exposure. He also aims to measure how performance may change and develop over time for those who have had this exposure.

His research investigates whether a computer-administered test known as the Halstead Category Test (HCT), can reliably and accurately measure paediatric cognitive impairment in those exposed to alcohol in the womb. After several years of using the HCT in his clinical practice at the North Star Paediatric Behavioural Health Hospital in Alaska, Dr Sperbeck saw that persistently low HCT performance would help identify prenatal alcohol exposure in cases where cognitive impairment was observable but alcohol consumption during pregnancy had been denied by parents or guardians.

The Halstead Category Test

The HCT can detect impairment in the prefrontal lobe, an area of the brain that is linked to a variety of complex behaviours. It was originally developed in 1947 by Dr Ward Halstead to measure

abstract reasoning, which is our ability to understand or solve complex issues using unfamiliar information. It has since been used to test executive functions such as concentration, visuospatial ability and deductive reasoning. It is a comprehensive test which is mainly nonverbal and involves participants reviewing 168 items of varying difficulty, split across six subsections.

Prior research has been undertaken using an abbreviated version of the HCT that only contains 68 items. This study aimed to compare the performance of children with traumatic brain injury with that of those with Attention Deficit Hyperactivity Disorder (ADHD). The results revealed no significant

differences between the two groups. In fact, the participants' scores were found to be in the normal range. The researchers felt the lack of sensitivity shown by this version of the HCT may be due to its reduced length.

More recently, research has been undertaken to assess the effectiveness of the HCT in measuring the cognitive performance of children who have been exposed to alcohol within the womb. This study involved two different age groups, younger children (5–7 years old) and adolescents (10–16 years old). As a control measure, children who had no previous prenatal alcohol exposure were included across both age groups.

Those with prenatal exposure obtained lower scores than children who had not been exposed to alcohol. These results were consistent across both age groups and are also what Dr Sperbeck had expected given his extensive experience using the HCT in clinical practice. Interestingly, adolescents in the slightly older group scored more poorly than the younger children. Understanding how scores on the HCT may change with age was noted by Dr Sperbeck to be the critical next step.

Keen to overcome some of the methodological flaws of earlier studies, Dr Sperbeck used the longer version of the test and sought to study a larger and more clinically representative group of children. He hypothesised that children with prenatal alcohol exposure or prior cognitive impairment would show a higher number of errors on the HCT than unimpaired children, across all age groups. He did not expect any variation between ethnic categories due to the test being largely non-verbal. Dr Sperbeck also hypothesised that in line with prior studies, errors would decline with age. Therefore, he expected older children to make fewer errors, on average, than younger children.

The Alaskan Context

This research took place in Alaska, a geographically large area comprising urban, rural and remote communities. This means that some of the population are unable to access routine medical, psychiatric and behavioural health services. As a result, Alaska experiences some of the highest foetal alcohol syndrome as well as accidental childhood brain trauma and infant mortality. For over a decade, Dr Sperbeck served as the

Chief Paediatric Neuropsychologist at North Star Behavioural Health Hospital in Anchorage, Alaska. All the children who took part in the research had been admitted to this facility which is Alaska's only inpatient paediatric behavioural health hospital.

The children who took part were aged 9 to 17 years old. There was a mix of ethnicities representing the different communities living in Alaska, with the majority of the 813 children being either Caucasian or Alaska Native/American Indian. The participants were split into three different groups. The first group of children had already been classified as prenatally exposed to alcohol. There was a higher percentage of Alaska Native and American Indians within this group, consistent with previous prevalence studies. The second group had a history of cognitive impairment, but no links had been made to alcohol exposure. The remaining group had normal cognitive functioning and no history of prenatal alcohol exposure.

Offering Hope for the Future

Importantly, the results demonstrated that the HCT could distinguish between children who had experienced prenatal alcohol exposure, those with cognitive impairment, and those with normal functioning. This confirmed the sensitivity and appropriateness of the test in these groups of children. As predicted by Dr Sperbeck, children with foetal exposure and cognitive impairment were more likely to have higher error scores on the HCT, across all age groups.

Also as predicted, better executive function was recorded in older children across all three study groups. Dr Sperbeck believes these data suggest that over time there may be improvements in executive functioning for children who have cognitive impairments, as well as those who don't. This critical finding of improved performance throughout development offers important hope for the futures of children affected by alcohol exposure.

Although there is no specific treatment for prenatal alcohol exposure, the possibility that those affected have the ability to improve their cognitive performance over time due to neural plasticity and an enriched learning environment.

Dr Sperbeck's findings were also in contrast with prior research using a shorter version of the HCT test in which the HCT was not sensitive enough to detect higher error rates for cognitively impaired children. Thus, Dr Sperbeck has shown that the longer version is a much more sensitive measure. Furthermore, his large sample of participants not only provides robust results that we can have confidence in but also can serve as a normative sample for future research and clinical application.

Finally, the HCT was found to be statistically unbiased, meaning it was not influenced by gender or ethnicity. The nonverbal nature of the test likely helped make it more culturally fair and Dr Sperbeck emphasizes that such measures must be appropriate for global use.

A Sensitive, Fair and Reliable Measure

Dr Sperbeck believes further studies should take a longitudinal approach, observing children throughout childhood and adolescence. This study was cross-sectional in design, meaning that the children were assessed at a single given point in time, but nonetheless confirmed the robustness of the HCT.

Overall, results from the study provide strong support for the use of the HCT as a sensitive, fair, and reliable test for assessing the executive function of children aged 7 to 19 years old. It highlights the importance of using an easily administered and evidence-based test for these vulnerable children. This research also raises awareness around the ongoing need for education, support, and prevention programmes to help reduce prenatal alcohol exposure, especially in regions such as Alaska.

Meet the researcher

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Dr David Sperbeck completed his Doctorate in Clinical Psychology at the University of Rochester in New York. He then served as a Forensic and Clinical Neuropsychologist for the state of Alaska from 1982 to 2005 and then the Chief of Paediatric Neuropsychology Services at North Star Behavioural Health Hospital in Anchorage, Alaska, until 2019. He was appointed Clinical Professor of Psychiatry at the University of Washington School of Medicine from 1985 to 2020. Dr Sperbeck currently works in private practice, where in addition to consulting, he provides threat assessment, law enforcement and clinical supervision services. Over the course of his career, he has authored more than 150 papers relating to neurodevelopmental disorders and the assessment of these.

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FURTHER READING

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SAFETY LEARNING: EXPLAINING AND TREATING MALADAPTIVE COVID-19 CONCERNS

Safety signals are learned cues that predict the non-occurrence of an aversive event and are effective in inhibiting fear and maintaining fear-motivated behaviours in anxious individuals. However, the role of inhibitory learning mechanisms in producing 'conditioned inhibitors' in response to safety signals has received little attention. The need to better understand this has become more pressing given the increased levels of health anxiety and safety behaviours resulting from the COVID-19 pandemic. **Professor Helen Cassaday** at the University of Nottingham and colleague **Dr Meghan Thurston** have evaluated the role that safety learning plays in anxiety, inhibitory learning and concerns about COVID-19.

Understanding Fear and Anxiety in the Evolutionary Context

Fear and anxiety are entirely normal – in fact, essential – emotions. When we are anxious or frightened, adrenalin is released into the bloodstream, increasing our heart rate and the blood flow to the heart and muscles. This hard-wired 'fight or flight' response is critical to our survival.

In an evolutionary context, (re)actions which remove threats enhance our survival and are thus reinforced through natural selection. Those who do not respond sufficiently to a threat are less likely to survive, and therefore, appropriate levels of anxiety and fear are necessary.

There is a need to better understand the functional role of fear and anxiety in our modern times. Too much anxiety can affect well-being, whereby some individuals over-respond to potential threats by developing maladaptive avoidance behaviours to remove themselves from the situation. So, while responding to threat can be a proportional and appropriate response, depending on the situation, it may also be harmful and counterproductive.

The recent COVID-19 pandemic is a good example of the demand for a delicate balancing act in how we respond to threat. Individuals who failed to avoid the threat may have put themselves and their families at increased risk of contracting the virus. On the other end of the spectrum, some individuals experienced severe health anxiety and adopted safety behaviours which were counterproductive.

The COVID-19 pandemic has put a new perspective on the complexity of how we respond to threat and the presumptions that safety behaviours should be eliminated. As such, current therapeutic options need to be re-evaluated. Professor Helen Cassaday from the University of Nottingham and colleague Dr Meghan Thurston recently published a perspective article on the role of safety learning in anxiety, based on experimental models of inhibitory learning. Their evidence-based analysis progresses our understanding of the role of safety learning relating to COVID-19 and its impact on mental health.

Safety Learning and Anxiety

Learning about threats is a fundamental survival behaviour in which we associate previously neutral stimuli with adverse events, and as a consequence initiate defensive behaviours to prevent direct harm. However, the failure to inhibit these threat responses in environments which are actually safe means that these survival behaviours can become dysfunctional and contribute to inappropriate and excessive levels of anxiety.

Safety learning is the process by which a stimulus becomes associated with the absence of threat. It is currently a poorly understood concept compared to threat learning but is emerging as a topic of interest. Individuals adopt safety behaviours in an effort to prevent their fears from becoming realised and

to allow them to feel more comfortable in situations they are anxious about. If an individual believes that a situation will not go well, they are likely to feel anxious and have the urge to avoid the situation.

Short-term safety behaviours can give a sense of relief but in the long term, they often prove unhelpful. Animal studies confirm that safety signals – learned cues that indicate threat is unlikely – moderate reaction to stress and help to buffer the effects of uncontrollable stressors.

Although there are effective treatments, the underlying mechanisms of various anxiety disorders are still not fully understood and they have multiple causes. Individuals who have anxiety disorders report awareness of a variety of safety signals – such as the presence of a trusted person and the knowledge they have medication to hand. The main treatment is cognitive behavioural therapy, in which one approach is to encourage individuals to drop their safety behaviours. Clinically, there is mixed evidence in support in terms of effectiveness but it remains the generally favoured approach. Removal of the safety behaviour may be combined with strategies for the individual to reflect on the absence of a negative outcome occurring.

Safety Learning in the Context of COVID-19

The most theoretically sound experimental model of safety learning is arguably conditioned inhibition. Conditioned inhibition is a more general learning phenomenon, in which a stimulus that predicts the absence of an otherwise expected outcome comes to control how an organism (be that an animal or human subject) responds to it.

Scientists are becoming increasingly interested in the development of safety behaviours in humans and how best to manage these therapeutically. The safety learning approach has yet to be applied to the context of understanding the mental health impact of the COVID-19 pandemic but it has clear relevance. For example, people may initially sanitise and wash their hands to reduce the risk of infection, however, the safety signals provided by the smell of sanitiser and soap will come to secondarily reinforce this behaviour. Individuals with obsessive-compulsive disorder have been identified as being particularly susceptible to the development of such behaviours. However, there is also some evidence of increased anxiety and bias towards the direction of attention towards virus-related threats compared to pre-pandemic levels in the general population as well.

Theoretical and Therapeutic Implications

Professor Cassaday and Dr Thurston conclude that while remote cognitive behavioural therapy has been somewhat effective as COVID-19 restrictions relaxed and the immediate threat waned, there is much yet to be explored in the emerging application of interventions relating to COVID-19. Safety signals prevent conditioned fear from being removed and their removal or extinction has been the focus of therapeutic intervention for anxiety disorders to date.

Unfortunately, COVID-19 has resulted in a complex and ever-changing situation. As new variants arise and the threat waxes and wanes, safety behaviours will need to be judged in this context as they may prove entirely rational. As such, each individual's risk, vulnerability and personal situation will need to be taken into account when deciding their best course of action. If, as we hope, COVID-19 is now behind us, the next pandemic may still be around the corner, and we must prepare. Similar considerations will apply. Professor Cassaday and Dr Thurston argue that perhaps the most pressing need is to identify whether safety behaviours are increased or decreased in connection with different anxiety-related disorders and concerns.

Meet the researchers

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Professor Helen Cassaday received a degree in Experimental Psychology from the University of Oxford before going on to complete a PhD in psychopharmacology at the Institute of Psychiatry at the University of London. She returned to Oxford in 1990 and worked as a Postdoctoral Research Associate in the Department of Psychology before moving to the School of Psychology at the University of Nottingham in 1996, where she initially took up the post of Lecturer. Throughout the years, she progressed through the academic ranks at the University of Nottingham, being promoted to full Professor of Behavioural Neuroscience in 2016, the position she still holds today. She has expertise and extensive experience in the fields of psychopharmacology, behavioural neuroscience and experimental psychology. Her research focuses on the underlying biology of associative learning processes which are fundamental to normal cognition.

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Dr Meghan Thurston currently works as a Consultant Clinical Psychologist in the NHS. She completed a BSc(Hons) in Biology, and a PhD in Behavioural Neuroscience at the University of Nottingham before completing her Doctorate in Clinical Psychology at the University of Leicester. Her academic work has focused on anxiety disorders, inhibitory learning, and mental health in transgender healthcare. This has led to several publications in peer-reviewed journals. Since qualification, Dr Thurston has worked in Paediatrics at the Royal Derby Hospital and in Transgender Healthcare at the Nottingham Centre for Transgender Health where she is the Consultant Clinical Psychologist and Lead for Psychology and Psychotherapy. Dr Thurston continues to maintain involvement in research and has a passion for education, training, and supervision.

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SPEAK AND I'LL TELL YOU WHO YOU ARE

While international students are common at universities in the English-speaking world, it is unclear how much the language skills of these students and their ethno-racial backgrounds affect their educational and social experiences. **Professor Kim McDonough** from Concordia University, Canada, and **Professor Masatoshi Sato** from Universidad Andres Bello, Chile, conducted research with colleagues which resulted in some very surprising findings.

The Benefits International Students Bring

Unquestionably, universities strive to recruit and educate international students due to the diversity and income they bring. In the English-speaking world, after the USA and Australia, Canada educates the third highest number of international students, with approximately 300,000 of them studying in the country in 2018–19, and this number is increasing at a rate of 15% a year. Approximately 50% of this student population comes from Asia, mostly China and India.

International students contribute over $22 million a year to Canada's economy, and the benefits do not stop there. After completing their education, highly trained international students are ideal candidates to fill gaps in the workforce of the nation. Indeed, a significant number of them contribute this way, either by gaining short-term employment on 3-year temporary work permits or by becoming permanent residents.

Not Quite an Idyllic Picture

Given the economic importance of international students, the Canadian Bureau of International Education regularly evaluates their experiences. A recent survey of 14,000 foreign students indicated that the majority were 'satisfied' or 'very satisfied' with their experience, describing Canada as a welcoming and friendly country. However, changing political attitudes towards immigrants and the COVID-19 pandemic triggered an increasing anti-Asian sentiment in some pockets of the general population.

Professor Kim McDonough (Concordia University, Canada), Professor Masatoshi Sato (Universidad Andres Bello, Chile), and their colleagues wondered whether such negative feelings affected the relationships among university students. To answer this question, the team devised some probing experiments designed to detect unconscious bias against international students.

How Do Linguists Detect Discrimination?

To understand the work of the group, we need to start with the researchers' explanation of linguistic stereotyping. The basic premise is relatively simple: we are constantly being judged by people around us, based on how we speak. Even within the same country, certain regional accents, or the use of minority languages can alter how people perceive an individual.

As Professors McDonough and Sato tell us, subconscious conclusions drawn by listeners can be divided into two categories. Some 'assess' the speaker's social status, level of education, social class, ambition, intelligence and competence. Scientists call these 'status traits'. The other group of characteristics, the so-called 'solidarity traits', are value judgements on the trustworthiness, kindness and helpfulness of the individual who is talking. Surprisingly, the accent of a person can even affect their perceived attractiveness.

When it comes to racialised speakers, the complexity of these subconscious judgments is illustrated by a phenomenon called 'reverse linguistic stereotyping'. This scientific term can be explained with a relatively simple example: when listening to a racialised individual, some listeners will still perceive them as less well-spoken and harder to understand, despite English being their first language. In this case, subjective judgement about accent is influenced by how the speaker looks.

Experimental Setup with a Twist

The researchers recorded short speech samples of male and female international students discussing academic and everyday topics. Those

talking were either European (German or Romanian), Chinese, or South Asian (Urdu). These recordings were then played to 80 fellow students – 'raters' – 25% of whom were native English speakers, while the remaining 75% represented a diverse group of 22 different language groups.

These students were asked to give an opinion on how strong the speaker's foreign accent was and how easy, or difficult, they were to understand. In further questions, those listeners were also asked about how willing they would be to interact with individual speakers, share lecture notes, or participate in group projects involving them. Additional questions prompted listeners to rate the speakers' intelligence, trustworthiness, and competency and to give an opinion about how pleasant, sincere, and attractive the speakers were, thus rating their status and solidarity traits.

The scientists employed a key twist in these experiments: while playing the same speech sample, the raters were shown different faces – implying that the speaker was European, Chinese, or South Asian. And those faces were matched with different types of accents.

Evidence for Discrimination: Some Good News

Previous research documented that American students rated their European classmates as more understandable and less accented than those students who were from Asia or Latin America. Similarly, during the experiments carried out by Professors McDonough and Sato and their colleagues, listeners generally reported that they found European students easier to comprehend and rated them as more intelligent and likeable. Given that 75% of the raters consisted of a diverse group with an international background, who spoke English as a second language, this preference was somewhat unexpected.

However, despite the lower ratings for Asian speakers, there were some encouraging findings. Firstly, listeners attached more positive characteristics to speech samples they found easier to understand, irrespective of the ethnic background of the speaker. In addition, receiving positive or negative ratings mostly depended on how easy the speech sample was to comprehend and the strength of the accent of the speaker appeared less important. Crucially, putting a European face to an Asian speech sample did not improve the perception of the speaker, indicating that the students listening to the speech samples were not influenced by physical appearances.

Explanations and Practical Considerations

As Professors McDonough and Sato tell us, there could be two explanations for the observed preference for European voices. One of these could be racial/ethnic discrimination. The other reason is that individuals are simply trying to avoid the extra 'work' of deciphering unfamiliar language use. The finding that listeners were not influenced by the appearance of the speakers indicates that racial/ethnic discrimination is not widespread amongst the students participating in the experiments, and their preferences were mostly due to the extra mental challenge of trying to understand what was being said. A caveat here is that the listeners resided in Montreal, Canada, a multilinguistic and multicultural city. So presumably, the listeners were already accustomed to different faces and accents.

Professors McDonough and Sato were particularly encouraged by this finding as it points towards the ways Concordia University may help the integration of international students into the academic community. While ethnic/racial discrimination is notoriously difficult to break down, instructors and administrators can easily devise activities in which international students can participate and establish social interactions with their peers.

Some Limitations and Future Research

Given that this work has already produced scientific and practical benefits, Professors McDonough and Sato are already planning on extending this avenue of research. As they point out, the number of speech samples was relatively low, so it was impossible to evaluate whether male and female speakers are rated the same way. Furthermore, they are concerned that showing a stationary image while listening to speech samples may not elicit unconscious bias. Therefore, the scientists are planning a larger study that involves showing video recordings of the speakers. In addition, they also plan to elicit a more comprehensive view of students' attitudes towards international students using interviews and questionnaires. As Professors McDonough and Sato point out, this work will help the education of international students worldwide.

Meet the researchers

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Professor Kim McDonough initially trained at the University of Michigan, where she graduated with a BA in Political Science and Studies in Religion in 1992. After teaching English in Thailand for four years, she continued her studies at Michigan State University, where she obtained a MA degree in Teaching English for Speakers of Other Languages in 1998. Finally, she completed her PhD degree in Applied Linguistics at Georgetown University in Washington DC in 2001. She started as an Assistant Professor at the Division of English as an International Language at the University of Illinois Urbana-Campaign the same year. In 2005, Professor McDonough moved to Northern Arizona University where she became an Associate Professor in Applied Linguistics. She joined the Department of Education at Concordia University in 2010, where she became a Professor of Applied Linguistics in 2015. While at Concordia University, she served as a Canada Research Chair in Applied Linguistics from 2011 to 2021. Her primary research goal is to identify how interaction facilitates second-language learning, and she is also interested in developing written and oral communication tasks that promote peer interaction in second-language classrooms. Her most recent research investigates the role of visual cues during face-to-face conversations.

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Professor Masatoshi Sato was born and raised in Osaka, Japan, and obtained his BA in Cross-Cultural Studies from Kobe University in 2004. During his undergraduate studies, he completed an MA certificate in Teaching English to Speakers of Other Languages at the University of New Mexico, with an ambassadorial scholarship from the Rotary Foundation. He then moved to Montreal, Canada, where he completed a MA degree in Second Language Education (2004–2006) and a PhD in Educational Studies (2008–2011) both at McGill University. Since 2012, he has been teaching at the Universidad Andres Bello, where he trains pre-service and in-service second language teachers. He is the recipient of the 2014 *ACTFL/MLJ Paul Pimsleur Award* and is currently the Editor of the international journal *Language Awareness*. He is also the Co-Director of *TESOLGraphics* whose aim is to facilitate communication between researchers and practitioners related to second language teaching. His research interests include instructed second language acquisition, peer interaction, metacognition, corrective feedback, learner psychology, teacher beliefs, race and accent, and the research-practice relationship.

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FURTHER READING

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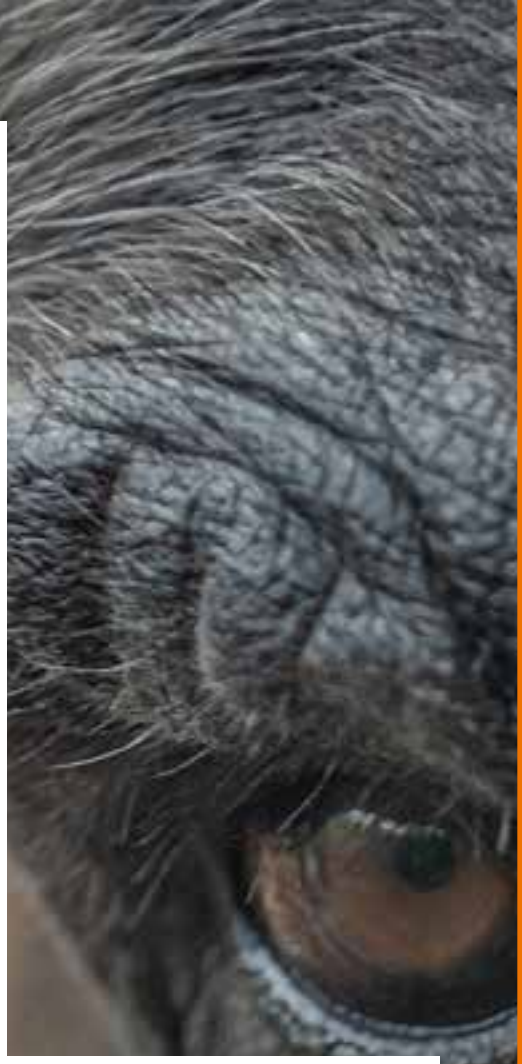
THE NEW SCIENCE OF ANIMAL CULTURE, CONSERVATION AND WELFARE



An abundance of evidence converges to suggest that humans are not the only species to create culture. Field and laboratory studies in animals have demonstrated that social learning and the transmission of the traditions that make up a culture can be found across many different species including primates, birds, fish and even insects, and in many different contexts. **Professor Andrew Whiten** at the University of St Andrews and his extensive network of collaborators are pioneering conceptual and methodological frameworks to promote the conservation and welfare of animals from a scientifically rigorous perspective.

Article written by Dr Catherine Deeprose.

Culture: A Uniquely Human Characteristic?

Culture has such a profound impact on our lives that it even shapes our understanding of what it means to be human. From foraging techniques and language to science and religion, our complex cultures reflect the social learning we garner from others and the transmission of traditions through generations. But is culture really a uniquely human characteristic? Research over the past 70 years has accumulated to suggest that, contrary to long-standing belief, humans are not the only animals to create cultures that spread across populations and generations.

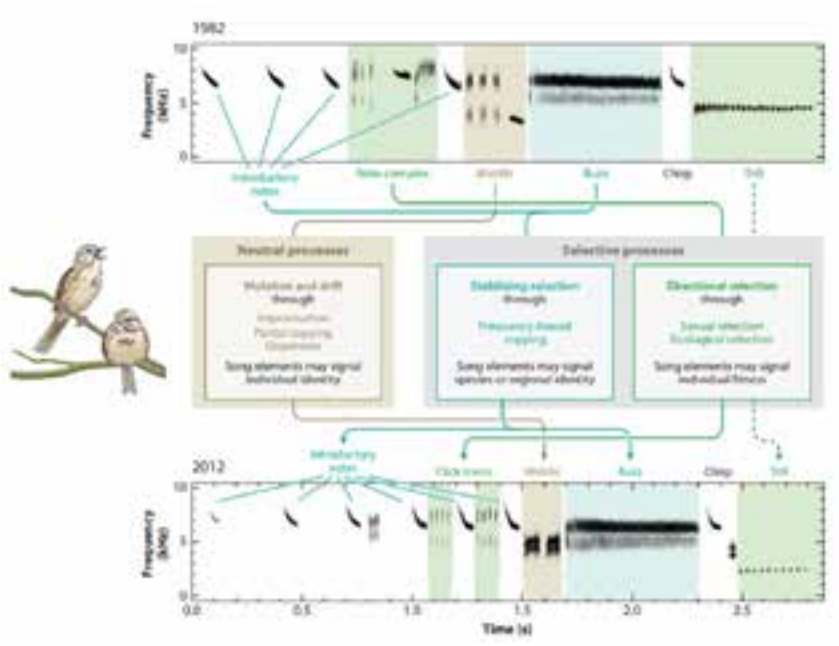
As early as in the 1940s, UK blue tits and great tits were observed tearing open aluminium seals on milk bottles to syphon off the cream inside. This behaviour, first spotted in only a very small number of birds, eventually spread to entire tit populations across the country. Not long after, Japanese macaque monkeys on Koshima islet were observed slowly but surely taking up the washing of sand-covered sweet potatoes in water before eating, adopting the behaviour first observed by researchers in a young female named Imo. Finally, evidence in support of vocal cultures in animals arose through the identification of regional dialects in male sparrows in the wild, acquired in around the first 100 days of life. Laboratory experiments confirmed that many songbirds need to learn their songs from the previous generation.

These early but compelling observations were followed by further evidence that culture achieved through social learning and the transmission of traditions can be found across many different species including primates, birds, fish and insects in both naturalistic (wild) and laboratory settings. Research with chimpanzees has been particularly influential, with demonstrations of multiple cultural

traditions – such as tool use, grooming and foraging techniques – being found to have distinct features transmitted to others over time.

Social Learning: From Mothers and Others

In a review article published in 2018 by Professor Andrew Whiten (University of St Andrews) and Professor Erica van de Waal (University of Lausanne), three main phases of social learning were identified in the lives of many primates.



The evolution of swamp sparrow song in a 30-year study. From Annual Review of Ecology, Evolution, and Systematics, 2019, with permission.

The first describes the learning acquired by infant primates from their primary caregiver, usually their mother. In the main, primate mothers carry and breastfeed their infants for the first months (in apes, years) of life, and these maternal interactions provide many opportunities for social learning. The researchers cite the experimental example of groups of wild vervet monkeys fed corn dyed either pink or blue, with one colour having an additive making it too bitter to eat. Although young suckling monkeys were too young to eat the corn at this time, when presented the dyed corn four months later when they were weaning – with neither colour now containing the bitter additive – all the young monkeys ate only the colour chosen by their mother, indicating social learning of food preference.

In the second stage, young primates extend their repertoire of social learning beyond that provided by their mother to others within their widening social circle, further expanding their knowledge and skills. In a decade-long study of brown capuchin monkeys and their use of stones to crack open hard-shelled nuts, younger capuchins were found to preferentially observe older monkeys with the greatest expertise, enhancing their social learning of this all-important skill.

Finally, the third stage, dispersal, occurs when a new group member engages in social learning of the dynamics and knowledge of the group they have joined. Returning to the study of wild vervet monkeys and the dyed corn described above, the same researchers observed that new males to the group were quick to adopt the food preference (i.e., the colour of corn) of the new group, even when this was contrary to the preference in the previous group from which they came.

The Cognitive Underpinnings of Social Learning

Social learning and cultural transmission require sufficient cognitive capacity – that is, the capability to undertake the mental actions and processes that lead to knowledge and understanding. Social learning takes differing forms across different species, and these vary significantly in complexity and thus, cognitive underpinnings.

At the simpler end of the spectrum, there is associative learning, in which a new response becomes associated with a particular stimulus. For example, bumblebees who observe either trained or artificial bees foraging from either orange or green flowers later demonstrate the same preference. This type of learning may be the most common across many animal species.

The copying of complex behavioural routines occurs at the opposite end of the spectrum. Termite fishing by chimpanzees is a relatively complicated behaviour, requiring a number of steps including the selection of a suitable tool (e.g., a stick or blade) to extract the insects from the termite mound or subterranean chambers. Although a behaviour found in several different chimpanzee communities, researchers have identified many distinct local actions used for termite fishing in different communities, indicating cultural diversity. Similarly, recent research has shown that groups of whales and dolphins have specific and unique vocal repertoires, food preferences and other behaviours.

Implications for Conservation

The protection of biodiversity – the rich biological variety and variability of life on Earth – is a key aim of conservation. As such, efforts are typically geared towards sustaining natural populations of wild species, taking into account the genetic, ecological and demographic risk factors for their demise. Until recently, this involved little consideration of social learning and culture.

Supported by the wealth of scientific evidence illustrating social learning and culture across a wide and diverse range of species, leaders in the study of animal behaviour are now calling for this knowledge to be applied to the development of conservation priorities and practice. In a significant step forward led by Dr Philippa Brakes, the importance of animal culture was recently brought to the fore by the

Credit: Kokolopori Bonobo Research Project

Convention on the Conservation of Migratory Species of Wild Animals, an environmental treaty which operates under the aegis of the United Nations Environment Programme.

Researchers point to the distinct role that social learning plays in the transmission of behaviours – and also note the rapid speed at which this can be observed (intra-generationally) in contrast to behaviours that are genetically inherited (between generations). Furthermore, the breadth of behaviours associated with social learning, including foraging, migration routes and mate choice, can all be critical to conservation efforts. Finally, when social learning gives rise to the transmission of information through groups, this can lead to culturally specific behaviours that are sustained both over time and through generations. These are also of conservation value, not least because the transmission of locally specific knowledge and behaviours increases the likelihood of survival for populations at risk.

We are still some way off from truly embedding our understanding of animal social learning and culture into conservation policy and practice. To achieve this, much closer collaborations are required between scientists and conservation policy-makers and practitioners, driven forward within the context of appropriate conceptual and methodological frameworks.

Implications for Animal Welfare

Learning, including social learning, allows animals to maximise their health, longevity, and reproductive success. While the benefits of this are readily apparent for animals in the wild, what about those kept in captivity? Dr Lydia Hopper (Johns Hopkins University) takes a particular interest in utilising recent advances in our understanding of social learning and culture in animals to improve the care and welfare of those in captivity. For captive animals, opportunities for learning can be cognitively enriching, conferring welfare benefits. Additionally, captive animals are typically exposed to a vast array of social information from different sources, including their cage mates, other animals housed nearby, and also humans, providing multifaceted opportunities for social learning.

Among many uses, social learning can be employed to enhance socialisation with others. One study in chimpanzees demonstrated that their tendency towards food sharing could be increased by partnering one chimpanzee with another that shared food with them. Afterwards, the chimpanzee who had been the recipient of the shared food was more likely to share their own food with others. More harmonious social environments within groups of marmoset monkeys have also been created by allowing them to 'overhear' positive vocalisations made by individuals in neighbouring enclosures, thus fostering positive cultural norms.

In addition to socialisation, enrichment of the environments of captive animals is fundamental to promoting good welfare, and here, social learning again provides a valuable tool. For example, when part of a social group, many animals are more likely to explore novel spaces, eat novel food and engage with novel stimuli (e.g., unfamiliar veterinary equipment) meaning that presentation to social groups rather than individuals is likely to be more successful in social species. Relatedly, social learning in this form has the potential to maximise training efforts, allowing animals to participate in procedures such as those required for husbandry or research with minimal stress and intervention.

Such applications are not limited to animals living in captive settings. Researchers have proposed ways in which studying what and how animals socially learn can strengthen our understanding of wild animals' welfare, promote the maintenance of key behaviours, and mitigate negative human-animal interactions. Like captive animals, many wild animals are exposed to anthropogenic stressors. Seeking a comprehensive picture of the various social influences that animals experience will be key to enhancing the ways we care for and conserve animals across settings.

Building on Scientific Foundations

Over the last 70 years, our knowledge and insight into the social learning and cultures of animals have expanded exponentially. We can no longer consider culture to be a uniquely human characteristic. But equally importantly, these scientific advances can now be used to propel and expand conservation efforts of animals in the wild, and to improve the management and welfare of animals, both in captivity and in the wild.

Meet the researcher

Professor Andrew Whiten
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Andrew Whiten has played a leading role in developing the field of animal culture, particularly in primatology. He collaborated with Phillipa Brakes and colleagues in advancing policies linking animal culture and conservation and Lydia Hopper completed her PhD under his supervision. Professor Whiten completed his PhD in animal behaviour at the University of Bristol in 1972 followed by a Research Fellowship at the University of Oxford. He was appointed Lecturer in Psychology at the University of St Andrews in 1975 and later a Reader and Professor. He was promoted to a distinguished Wardlaw Professorship in 2001 and is now Emeritus Wardlaw Professor. Over the course of his career, Professor Whiten has been instrumental in establishing the Centre for Social Learning and Cognitive Evolution (Founding Director 2003–2016) and the 'Living Links to Human Evolution' Primate Research Centre (Founding Director 2008–2015). An elected Fellow of the Royal Society of Edinburgh, British Academy and international Cognitive Science Society, he has been the recipient of a multitude of awards, including the Delwart International Scientific Prize (2001), Rivers Memorial Medal (2007), Osman Hill Medal (2010) and Sir James Black Medal (2014)., Professor Whiten is the first scientist to be awarded both the Royal Society of Edinburgh Senior Prize and Medal in Life Sciences and Senior Prize and Medal for Public Engagement.

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SOCIAL SCIENCES & HUMANITIES

THE NEGLECTED CONSEQUENCES OF CHILD LABOUR

Child labour is a major social problem that contributes to poor physical health and lower educational achievement. **Professor Alberto Posso** (Royal Melbourne Institute of Technology) worked with **Professor Simon Feeny** (Royal Melbourne Institute of Technology), **Dr Ahmed Skali** (University of Groningen), **Professor Amalendu Jyotishi** (Azim Premji University), **Dr Shyam Nath** (Amrita University) and **Dr P. K. Viswanathan** (Amrita Vishwa Vidyapeetham) to address important gaps in the literature by conducting a large-scale study of children in rural areas of India. This work confirms the hugely negative impact of child labour on psychosocial well-being and opens up important implications for policy, practice and future research.

A Symptom and a Cause of Poverty

The International Labor Organization state that child labour deprives children of their childhood, potential and dignity, and harms their physical and mental development. Despite these deleterious consequences, recent reports estimate that globally, there are 160 million children aged engaged in child labour – representing an increase of 8.4 million in the last four years alone. And due to the impacts of COVID-19, millions more children are at risk.

As such, child labour represents a long-standing and challenging social problem in developing countries. India alone is responsible for 6% of child workers across the globe. Here, children typically live in rural areas and undertake agricultural or cultivating work.

It is likely that child labour is both a symptom and a cause of poverty. Not only do children engaged in labour achieve lower levels of education, but their physical health can also be jeopardised. Less is known however about the psychosocial and mental health impacts. In particular, previous studies have not been concerned with identifying a causal relationship between child labour and psychosocial well-being, while most research has only focused on children living in urban locations such as towns and cities.

Studying Child Labour in Tamil Nadu

Professor Alberto Posso from the Royal Melbourne Institute of Technology worked with colleagues Professor Simon Feeny (Royal Melbourne Institute of Technology), Dr Ahmed Skali (University of Groningen), Professor Amalendu Jyotishi (Azim Premji University), Dr Shyam Nath (Amrita University) and Dr P. K. Viswanathan (Amrita Vishwa Vidyapeetham) to identify the effects on various dimensions of child labour on the psychological well-being of children in Tamil Nadu, a predominantly rural and agricultural State in southern India. The researchers collected data between June and September 2018, as this mid-to-late summer period meant

children were most likely to be working. They randomly selected households with children aged between 12 and 18 years old, and on completion, had collected data on 947 children from 750 households across 20 villages. Just under half the children were female.

Of the surveyed children, 171 were defined as engaged in child labour, i.e., working in exchange for payment in any form (e.g., money, food), either as a regular commitment or as a less formal arrangement. All children completed established questionnaire measures of happiness, hope, emotional well-being, self-efficacy, fear (being scared) and stress, and provided demographic details (e.g., age, gender, number of siblings). Adult respondents in each

household provided information on wealth and their typical household expenditure to provide greater insight into the economic context of each child.

The Undeniable Impact of Work

Analyses confirmed that the children undertaking work reported lower levels of happiness, emotional well-being, self-efficacy and hopefulness than their non-working peers. They were also more stressed (although this observation wasn't statistically supported) and working and nonworking children reported similar levels of fear.

Looking more closely at the data, it was further confirmed that child labour was negatively and statistically significantly associated with happiness, hopefulness, emotional well-being and self-efficacy. In other words, labour was associated with markedly lower psychosocial well-being across most of the outcomes measured in this study.

The researchers also undertook a variety of more complex statistical analyses to allow them to confirm the robustness of their findings and take into account potentially confounding factors such as sex and the specific village each child lived in. The findings were clear, leaving no doubt that working goes hand in hand with poorer psychosocial well-being. The researchers further proposed this is a causal relationship, by which they believe that labour directly causes detriments to child mental health.

Given that poorer mental health of children is related to other negative outcomes in life, including lower educational achievement, substance abuse, violence and poor reproductive health, these findings point to child labour as an important and necessary target for intervention.

Addressing a Difficult and Complex Problem

The researchers acknowledge that combatting the psychological consequences of child labour will require policymakers to treat the root causes of child labour. They also acknowledge that this problem is extremely difficult and complex to address from a policy perspective. Unfortunately, banning child labour could have adverse impacts on child wages, which may lead to an increase in child labour to compensate for the reduction in a family's income.

With this in mind, the researchers have proposed that other types of interventions should be considered. For example, they suggest that family education programmes on how to identify mental health issues in children and adolescents could be developed, and that schools could step up their provision of mental health services, particularly in rural areas.

Critical Next Steps for Research

In addition to the proposals above, the researchers point to the next steps required from a research perspective. In their study, they did not measure how many hours children were working each week, so could not determine how the intensity of labour impacts psychological well-being. In addition, it would be useful to explore how different types of work impact children, as the demands of working in agriculture for example, differ in many ways from those involved in domestic labour. Finally, the current data did not allow the long-term consequences of child labour and future research should take a longitudinal approach to track the impacts on children throughout their development in young adulthood and beyond.

Meet the researchers

This research was led by the Centre for International Development at Royal Melbourne Institute of Technology in collaboration with colleagues at Amrita University and the University of Groningen

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Professor Alberto Posso completed his PhD in Economics at the Australian National University in 2008. After this, he completed several research and teaching positions and in 2019, was appointed as Director of the Centre for International Development at the Royal Melbourne Institute of Technology (RMIT) and also Professor at the same institution. Throughout his career, Professor Posso has published prolifically in the fields of international development, labour economics, health economics, economics of education, child labour, poverty, migration, international trade and applied econometrics. He has received significant funding to support his work and he has been the recipient of many awards, including the RMIT Vice-Chancellor's Research Excellence Team Award in 2021. He currently sits on the editorial board for Cuestiones Económicas and the Journal of Resilient Economies, and has been a highly active PhD supervisor, supporting the next generation of researchers in his field.

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NEW APPROACHES TO THINKING ABOUT AND ASSESSING READING IN THE DIGITAL AGE: NOTES FROM A U.S. SCHOLAR

Article written by Diana J. Arya, Ingrid Fidelli, and Catherine Deeprose

Reading has become increasingly complex over the past few decades, largely due to the rapid pace of technological advancement and the increasing availability of massive amounts of information, some of which may blur the lines between fact and fiction. Identifying better practices to teach young people to read and accurately assess their reading abilities is now of pressing importance. **Dr. Diana Arya**, an Associate Professor at the University of California, Santa Barbara, has been exploring sociocultural and historical considerations related to how children read and understand different types of content in the digital era.

The Need for New Literacy and Reading Practices

Learning to read and understand textual information is a crucial step in a child's education. Such reading entails more than simply decoding (sounding out words) or grasping the main idea – reading also requires learning how to make sense of and synthesize complex issues, and critically reasoning about topics rooted in different sociocultural contexts.

In our digital era, the Internet has brought forth information technologies and social media platforms that have fuelled the mass dissemination of information across many different formats, including written articles, images, videos, and podcasts. Learning to examine all these resources critically in their respective modalities is extremely important for young developing readers who need a great deal of practice in making sense of and critically reasoning about the ever-growing informational landscape if they are to thrive academically and professionally in the 21st century.

Despite this, current methods used to assess children's reading abilities in American classrooms still primarily focus on printed texts. Most commonly, reading skills are assessed by asking students to read written passages and extract the main ideas conveyed in them.

In many parts of the U.S., including California, most elementary school teachers assess their students by using commercially available tests that generally require students to read texts, directions, and prompts, interpret the meaning of what they are reading, and then select a correct answer from a list of options usually intended to fill a missing space within presented text. Unfortunately, such standardized, forced-choice tests may be inadequate for assessing the reading abilities of an increasingly diverse student population who must prepare for a future of sociocultural, political, economic, and informational complexities.

Dr. Diana J. Arya, Associate Professor and literacy scholar at the University of California, Santa Barbara, has been exploring the limitations of existing methods and materials for supporting reading development as well as the ways in which conventional assessments may limit our ability to understand children's reading skills in America's classrooms.

This important work highlights the potential that stories of human experience – for example, scientific discovery narratives – have for understanding core scientific concepts and issues, and how such textual narratives may help narrow the performance gap consistently observed between white and non-white student populations.

From Simply Decoding to Deep Understanding

There are a number of important concepts, practices, and processes that relate to the science of reading that seem to be unacknowledged in mainstream media. Most of the discussions and opinion articles within social media outlets focus on the practice of decoding (i.e., sounding out words in printed form), which is only a small part of the reading process. If

Piloted middle school text in the Critical Reading Assessment (each excerpted text was presented on separate slides).

this (sounding out words) was the only skill required of students to succeed in school, we would see different results on reading assessments.

Reading is far more than decoding letters or sounds – it requires an understanding of the meaning beyond what is explicitly presented, discerning intentions, and critically reasoning about the accuracy and potential biases of texts. In the present information-rich landscape, reading can also entail engaging with content on social media, through comments, 'likes', and group discussions. Information can come in many forms – written/printed words, images, data representations, video clips and GIFs, podcasts, and more.

Dr. Arya's recent studies highlight the limitations of current reading practices and assessments in elementary school, particularly within the context of learning from informational texts. Findings from research on school-based texts such as science textbooks have revealed a number of issues including a lack of context about how scientific knowledge came into being. This exclusion leaves little room for readers to view science as more than information, and even less room to imagine themselves as potential scientists.

Dr. Arya emphasizes the importance of teaching students from all backgrounds to not merely understand textual content but to also critically reason about the presented information by questioning the intentions of the author and asking what may be missing or underrepresented. Such critical engagement with texts can, in turn, help developing readers make better sense of the world around them and be mindfully aware of the different types of content they consume every day.

How Sociocultural Context Affects Scientific Reading

In a study conducted in 2021, Dr. Arya and colleague Dr. Andrew Maul set out to better understand how young children from different cultural backgrounds engaged with science discovery narratives. These are stories either written by scientists or narrations of the process through which scientists discovered new things.

Compared to traditional scientific texts, which simply present facts and information without explaining how they were discovered, science discovery narratives make visible to readers how a scientist, or group of scientists, came to learn something new about the world or beyond. Drs. Arya and Maul's previous work (published in 2012) suggested that science discovery narratives can improve student understanding and retention of key scientific concepts described in these texts, with even greater effects for culturally marginalized students.

In following up on this 2012 study, Drs. Arya and Maul asked 24 middle school students to read a series of science discovery texts and then interviewed them to understand how they perceived and related to these texts. They found that the sociocultural context of human experience was highly impactful on these young readers; the discovery narrative seemed to reduce the distance between the science and the students, making it easier for them to see themselves working alongside the discoverers.

Context matters, especially when reading. The sociocultural context represented in texts used in the classroom can make a difference in terms of how engaged readers are and what they take up from textual information. While this is a simple finding, the 2021 study shows that the more relatable and inclusive (or representative) texts are to readers, the more they take up or learn from such texts.

This study confirmed that the way in which scientific content is presented to students is very important. Typical textbooks that present decontextualized information about aspects of nature such as chemical reactions, biological phenomena, and so on, might thus be far less effective in explaining science to elementary students than discovery stories that make visible the historical and sociocultural contexts in which facts are realized and conveyed to the world.

A Culturally Inclusive Online Reading Assessment

In collaboration with graduate students at the University of California, Santa Barbara, Dr. Arya conducted another study published in 2022 that began with the development of the Critical Reading Assessment (CRA), which is designed to be conducted online or in person and to gauge a young learner's text comprehension and critical reasoning.

Recently, national literacy assessments (such as the National Assessment for Educational Progress, or NAEP) have increasingly foregrounded different modalities of digitized text—images, data representations, and even video clips. While developing the CRA, the research team conducted group discussions with young children from different backgrounds and revisited initial texts to improve their sociocultural relevance. 'As such, we chose to involve young readers from the very beginning to ensure that the textual content was engaging and that the language used appropriately aligned with each respective grade level,' explains Dr. Arya.

The 2012 and 2021 studies by Drs. Arya and Maul were founded on the firsthand accounts of discoveries by scientists (shown here are Galileo Galilei, George Washington Carver, Jane Goodall, and Marie Curie).

The CRA is administered one-on-one and begins with some questions about the topic selected for reading. The young student then reads the text presented on the screen along with embedded infographics or videos on their electronic tablets. The assessor follows by asking a series of questions about the information presented in the text, as well as open-ended questions exploring what they found most interesting, surprising, inclusive, exclusive, and perhaps unfair to others.

The team tested the effectiveness of their newly developed reading assessment in a pilot study involving 52 fourth-grade students, most of whom were from a Latinx background and spoke at least some Spanish at home. When asked about the assessment, these young readers highlighted the value of their inclusion in the assessment's development.

The students also found the use of different types of textual modalities (i.e., written text, videos, infographics, and so on) helpful when trying to understand the content, while some felt that the exclusive use of English in tests made it harder for them to convey all they had understood. Finally, the researchers found that questions prompting students to critically think about what they read and share their perspectives were very useful in assessing their comprehension and engagement levels. 'What was most insightful for our team was the statistically significant difference between the participants' performance on the CRA compared to their performance on the widely used standardized reading test that was administered by the participating school within the same time period,' notes Dr. Arya. 'We found that the school-based standardized test significantly underdetermined the students' reading abilities by an average of more than one grade level. This finding suggests that results from standardized tests may not adequately reflect the true abilities of students, particularly those from historically marginalized backgrounds.'

Fostering More Inclusive and Relevant Classroom Reading Practices

Overall, Dr. Arya's recent studies emphasize the need to develop new reading programs and assessments for American classrooms that represent the full range of reading skills and abilities needed for fostering critical consumers of information. The CRA (created at the University of California, Santa Barbara), is a valuable example that could soon inspire the creation of similar assessments.

According to Dr. Arya, educators, and policymakers must catch up with the times, which means that we need to see some alignment between the assessment and instructional tools for fostering reading skills in schools and what it takes—and will take—to be an effective reader today and, in the future. She further points to how texts are evolving and becoming increasingly multimodal, meaning that we are now seeing podcasts and infographics (e.g., data charts and even memes) in what we read every day. Sadly, the current reading assessments used widely in schools are wholly inadequate for gauging readiness for the complexities coming around the corner.

Dr. Arya believes that educators in America need more sensitive and useable tools to assess their students' reading skills so that they can better support them on their academic journeys. Strengthening young people's reading and comprehension skills would undoubtedly make them more prepared to navigate the complexities of the 21st century and the vast amount of information they encounter every day. She aims to have all textual resources, approaches, and assessments she has developed freely available to schools and families; some of these resources are available now through her Community Based Literacies website (www.cbleducation.org).

Meet the researcher

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Dr. Diana Arya (she/they) is an Associate Professor and literacy scholar in the Gevirtz Graduate School of Education at the University of California, Santa Barbara, as well as Faculty Director of the university-housed McEnroe Reading and Language Arts Clinic. They hold a Ph.D. in Education from the University of California, Berkeley; two M.A. degrees in Education Literacy and Special Education from the University of Michigan, Ann Arbor; an M.A. in Applied Linguistics from the University of Illinois; and a B.A. in International Business and Asian Studies from Florida State University. Dr. Arya's research, which is affiliated with their multi-program initiative called Community Based Literacies, converges at the intersection of multimodal, critical reading practices, intergenerational mentoring, and place-based, interdisciplinary learning with an emphasis on social, economic, and environmental justice. This work is guided by Dr. Arya's larger mission to contribute to long-needed transformations in American elementary and middle school literacy education.

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UC SANTA BARBARA

THE SIGNIFICANCE OF NOK CULTURE SCULPTURES IN NIGERIAN PREHISTORY

Peter Breunig is a Professor of Archaeology at Goethe University in Frankfurt, Germany. He has spent much of his recent career conducting in-depth analyses around the Nok culture, a prehistoric society based in central Nigeria. Much of his research has focused on uncovering the mystery surrounding elaborate terracotta sculptures, made by the Nok people over 2,500 years ago. Whilst there is much speculation around their purpose, Peter Breunig and his team have identified a spatial proximity to burial sites, indicating their usage in funeral rituals.

The Discovery of Elaborate Terracotta Sculptures

Elaborate art is associated even with prehistoric societies in the form of rock art, but often, the role it played, its meaning and its use elude us. Archaeologists have unearthed fascinating evidence demonstrating the existence of artistic sculptures dating back to the first millennium Before Common Era (BCE). In central Nigeria, evidence of rituals that experts believe unified peoples across large geographical areas was discovered in the form of remains of elaborate terracotta sculptures. Their creation provides an insight into the complex rites and spiritual beliefs that were in existence at the time.

The first known finds of such evidence date back to the 1920s. In the 1970s, British archaeologist Bernard Fagg published his key discoveries of elaborate terracotta sculptures unearthed in a region between the cities of Abuja, Jos and Kaduna in central Nigeria. Since then, there has been a high demand on the international art market for these sculptures as they are the oldest of their kind in sub-Saharan Africa. Sadly, this demand has led to extensive looting and the irretrievable destruction of contexts that represent the only possibility to gain more knowledge about the Nok culture to which the sculptures are commonly attributed.

Since their initial discovery, archaeologists have begun to question why these elaborate and intriguing pieces of art were created and what purpose they may have served. Peter Breunig, Professor of African Archaeology from the Goethe University in Frankfurt, Germany, has spent the last 15 years piecing together clues to understand more about why the sculptures exist and what they can tell us about the Nok people who lived and farmed in central Nigeria over 2,500 years ago.

Origins, Chronology and Lifeways of the Nok Culture

The Nok culture was originally thought to date back to the Early Iron Age, which began around 500 BCE in West Africa. Archaeologists in the first scientific excavation in the 1960s found evidence of iron smelting forges along

Deposition of broken terracotta sculptures at the site of Pangwari during excavation 2013. Credit: Peter Breunig.

with the terracotta fragments from artistic sculptures, which led them to believe both existed at the same time. More recently, Peter Breunig and his colleagues have revised this timeline to begin much earlier. They have studied new evidence from radiocarbon dating of plant remains, a method used to determine the age of an object by measuring the amount of a radioactive carbon isotope with the atomic weight of 14 (C14) that is present. The results from this process suggest that the Nok culture actually began around 1500 BCE – a millennium earlier than initially proposed. This is supported by evidence from the ceramics found at Nok archaeological sites, which show a stylistic development from 1500 BCE onwards.

Excavation of the site of Ifana showing terracotta depositions (centre and above left) in the neighbourhood of graves (below left and below right). Credit: Peter Breunig.

Life-sized Nok terracotta head unearthed at the site of Ifana. Credit: Peter Breunig.

The new Nok chronology developed from radiocarbon dates and ceramic analysis gives us an insight into how the Nok culture gradually evolved over time. The Nok culture existed for almost 600 years before the first terracotta sculptures appear in the archaeological record – and iron technology appeared at least a couple of hundred years later. Its traces disappeared sometime in the last centuries BCE.

The origins of the Nok culture are unclear and there is no evidence of preceding inhabitants in this area, meaning it is likely that the Nok people emigrated from another region, probably from the north, to settle there. Due to the acidic nature of the soil, no bones have been preserved. Archaeologists are thus unable to determine if they kept domestic animals or went out to hunt for their food. There were some animals amongst the artistic sculptures but none were domestic, typically representing snakes, birds or monkeys. Based on an analysis of the lipid residue found in ceramic pots, it has been identified that the Nok people were likely to have consumed leaves from plants such as jute mallow, amaranth, African eggplant, okra, cowpea and kapok, still widely used today. Interestingly, they also found traces of honey, which could also have been used as a food source.

It has been difficult to build a clear picture of the dwellings used by the Nok culture. Their houses were typically constructed using degradable materials and few remains have stood the test of time. From the limited evidence available, it appears settlements covered small areas with only a few huts on each site. This suggests a scattered settlement system with individual farmsteads or houses. Typically, we would expect subsequent generations to occupy the same dwelling or site, but it seems that new generations moved to different locations within the local area. This frequent relocation could be due to the rapidly depleting soil quality and moving might have helped to generate a better food supply. Despite these settlements being scattered and only inhabited for relatively short periods, Peter Breunig believes there was shared culture amongst these people. The main piece of evidence that links them is the discovery of the terracotta sculptures throughout the whole distribution of the Nok culture.

The Production and Style of the Terracotta Sculptures

The terracotta sculptures found in the Nok culture region are the oldest large-scale sculptures in West Africa and the tradition to produce them is confirmed to date back to the 9th century BCE. Production of the sculptures seems to have rapidly reduced, if not stopped, around 400 BCE and archaeological evidence of its presence since then is only rarely found, seemingly replaced by new ceramic styles and converging evidence pointing to a new group of people. What is particularly interesting about these sculptures is that despite being made for over 500 years, their style has remained consistent. Typically, stylistic changes would be expected, especially as it is a creative object that has been replicated by different generations of artisans. Peter Breunig has noted that despite being found in different locations and contexts, the same motifs reoccur.

A second notable feature is that all the sculptures are made from clay that is composed in a very uniform way. As there is no evidence of a central workshop, it appears that these sculptures may be made by wandering craftsmen, making their uniformity even more astonishing. It has been proposed that this disparate method of production may have been required to supply sculptures throughout the scattered settlement system. As they were only produced for a specific period of time, it is speculated that the sculptures were used for a specific purpose but then became obsolete. Peter Breunig has remained curious about why they were created and has undertaken in-depth research to shed light on their existence.

Searching for the Meaning of Nok Culture Sculptures

Over the years, there has been much speculation about the use of these magnificent sculptures. Some suggest they were shrines, which stood in farmers' fields to ensure a rich harvest.

Map illustrating the spread of Nok culture. Credit: Peter Breunig.

Others believe them to have an architectural function, as decorative capstones on the roof of round straw huts. When initially found near smelting forges, they were suggested to be part of religious or magical rites during the creation of iron.

Other notable theories suggest they are temple decorations, commissions from wealthy rulers or even the sign of a snake cult. However, most of these suggestions are merely speculations and based on very limited evidence. Peter Breunig believes that the location of these sculpture fragments could help to reveal the reason for their existence.

In 2016, Peter Breunig and his colleagues began an in-depth analysis of the spatial context of the remains. They reviewed the location of sculpture fragments within a number of excavated sites, and found that some fragments had been close to what is interpreted to be Nok burials. While no human remains have been preserved due to the soil acidity, burials can still be identified through a number of factors.

The first is the remnants of organic decaying matter, which is identified by a technique called X-ray fluorescence. Second, these can be identified by the array of goods buried, such as fine ceramics and stone necklaces. Next to some burials, large fragments of terracotta were found but none were intact, along with broken pieces of different sculptures that could not be matched. They looked to be purposely buried underground, sometimes on a bed of stones. In other instances, the stones lay amongst the fragments as if they were used as tools to destroy them. Charcoal remains were also found, providing evidence that fire was involved in the ritual.

Gaining Critical Insights into Ritual Complexity

Peter Breunig strongly believes that the proximity of the sculptures to the Nok culture burials indicates their use was as part of complex funeral gatherings or rituals. It is possible that the sculptures represented the dead. Importantly, this research provides evidence that counters some of the earlier theories around the purpose of the sculptures within Nok culture. In particular, it discounts the idea that they were an example of social complexity within this civilisation; previously the sculptures had been heralded as an indicator of inequality, hierarchy and nucleation of settlement systems.

Peter Breunig's analysis strongly suggests that these large sculptures first appeared in the early first millennium BCE, which is earlier than originally suggested and that they were used as part of funeral rituals. While some questions remain unanswered, Peter Breunig's fascinating research helps to solve the mystery of these elaborate sculptures, which were created with such care and precision over 2,500 years ago.

Meet the researcher

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Peter Breunig was appointed Professor of African Archaeology at Goethe University in Frankfurt, Germany, in 1992. This is the only chair for African Archaeology in Germany. Upon his retire-ment in 2019, he was appointed Distinguished Professor at the same institution, where he had taught and conducted research for almost 30 years. He specialises in prehistoric archaeology, especially African archaeology, and in 2009, became the director of a long-term project funded by the German Research Foundation focusing on the development of complex societies in sub-Saharan Africa, featuring the Nigerian Nok Culture. Peter Breunig has taken a holistic approach to his research into this prehistoric society covering chronology, settlement, distribution, re-gional diversification, material culture, economy and environment. From 2003 to 2017, Peter Breunig was the editor and then co-editor of the international and peer-reviewed Journal of African Archaeology. In addition to publishing numerous academic papers and books, he has re-cently written a chapter for The Oxford Handbook of Nigerian History, which focuses on the prehistoric developments in Nigeria.

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UNCOVERING AMERICA'S PRIMATE PET TRADE

Pets are loved and valued members of many households across America. Unfortunately, some owners opt to keep primates as pets – and this is not a good choice for either the primate or the owner. **Dr. Melissa Seaboch** and Sydney Cahoon of Salt Lake Community College in the USA are working to better understand the primate pet trade in the USA.

Primates: An Unsuitable Attachment

Pets offer us companionship and fun, and bring tangible benefits to our mental and physical health. In the USA, one-third of households include pets and while for many, dogs and cats are the most popular choice, some pet owners choose primates.

There is an overwhelming consensus from scientists and veterinarians that primates, our closest living relatives, are an inappropriate choice. For a start, many owners lack sufficient knowledge about how to properly care for primates, leading to welfare concerns surrounding nutritional deficiencies, injuries, and behavioural disorders. Primates are naturally aggressive, and thus, injuries to owners are not uncommon. Primates can also carry diseases such as rabies and salmonella which can be easily transmitted to humans.

A Scarcity of Research

The vast majority of research into the primate pet trade has taken place in, or close to, the countries which form the natural habitat of primates, such as the study of pet lemurs in Madagascar (where it is illegal to keep them as pets) as undertaken by Dr. Melissa Seaboch and collaborators.

In contrast, very little research has focused on the extent of the primate pet trade in the USA, or its regulation, and Dr. Seaboch was driven to find out more about the true scope of the problem. Working with former student Sydney Cahoon, she undertook a systematic study of six publicly available online exotic pet-trade websites in the USA. Five of the six websites had been in existence for over ten years, implying a well-established basis for trading.

Over one year (from June 2019 to June 2020), the researchers visited each website twice a month. For each advertisement, they noted the date the advertisement was posted, common name of the primate (e.g., marmoset, capuchin), sex, age, location, and price. The researchers also took care to verify, as far as possible, that each advertisement related to a unique and specific primate for sale, to avoid inadvertently overinflating the numbers recorded.

The Extent of the Problem

Over the study duration of one year, the researchers found 551 pet primates for sale. The most common were marmosets, followed by lemurs, capuchins and squirrel monkeys. Where sex was stated, the majority were males and most (almost 80%) were aged less than 1 year old.

Primates were found for sale across 22 states. Florida had the highest number, followed by Tennessee, Texas, Missouri, and North Carolina. The prices of each primate varied hugely, ranging from $500 for a capuchin or marmoset to $15,000 for a spider monkey. Perhaps surprisingly, the price was not dictated by size of the primates, with the one baboon and one mandrill identified for sale being marketed at close to the average price of the whole sample.

As only six websites were studied, these figures undoubtedly underestimate the true scale of the problem. The authors note that primates can be found for sale through a multitude of different avenues and vendors, including private and commercial breeders, auctions, social media posts and pet stores.

Why Are Pet Primates So Popular?

Despite the convincing evidence that primates do not make good pets and that humans do not make good keepers of them, the ongoing popularity of primates as pets is clear. Dr. Seaboch points to several possible drivers of this.

The media is a powerful influence on consumer decision-making, and the choice of pet is no exception. Sales of green iguanas increased after the release of the Hollywood blockbuster Jurassic Park, and after the release of Finding Nemo, sales of clownfish rocketed. Primates have been popularly featured in films for decades, and capuchins are regular Hollywood stars. Thus, perhaps unsurprisingly, capuchins were the third most common primate found for sale in this research. No pet chimpanzees were found for sale, most likely attributable to private ownership being made illegal in 2015. Previous research has shown that viewing primates such as capuchins in human environments increases our desire to own such pets, but as pet owners were not studied in the current research, further conclusions regarding the influence of media on the pet trade are limited.

Another potential factor is that owners of pet primates may typically underestimate the time, effort and knowledge required to provide appropriate care, meaning they are unable to make an informed or sensible decision about the suitability of a primate as a pet. They may also be compelled by the notion of primates as 'fashionable' or status symbols and eager to follow the example of celebrities such as Justin Bieber (who owned a pet capuchin) and other celebrities, bloggers, 'influencers' and so on, who have posed with primates on social media.

Marmosets were the most common type of primate for sale. Across different types of pets, there is an assumption that smaller animals are easier to care for and they also hold a particular value in terms of 'cuteness'. For these reasons, Dr. Seaboch notes that smaller primates, such as marmosets, may be preferred by buyers. From a seller's perspective, the comparatively high reproduction rate of marmosets maximises their potential for income generation. As with other types of pets, younger animals are often preferred by buyers over their older counterparts, as also evidenced in the current study.

Impact of the Pet Trade on Wild Primates

Dr. Seaboch believes that the pet primates she found for sale were bred specifically for this purpose and not taken directly from the wild. However, as noted above, seeing primates outside of their natural habitats, such as in captivity or on TV, increases the desire of people to have one of their own. This increases the illegal trapping of primates in the wild and also leads to a mistaken belief that many primates are not endangered, and thus, conservation efforts do not receive the support or recognition that they require.

Reducing Pet Primate Ownership

Primate pet ownership in the USA will undoubtedly continue to expand if steps are not taken to reduce it. One approach is to better educate potential primate owners on the negative consequences, such as disease transmission. Tax burdens have proven successful in changing human behaviour in other domains (e.g., reducing smoking by increasing tax on tobacco). But as primates are expensive anyway, it is unlikely this would be an effective deterrent and may even increase their attractiveness as status symbols. Federal regulation, such as the requirement for owners to hold permits may be more effective, if the trade is not to be banned outright. Dr. Seaboch argues that to reduce the pet primate trade, the critical next step is to better understand the reasons why people want pet primates in the first place.

Meet the researcher

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Dr. Melissa Schaefer Seaboch earned her M.A. and Ph.D. in Anthropology from Arizona State University in 2011, with an emphasis in Primatology. She is a Professor and Department Chair at Salt Lake Community College. She has conducted research on psychological well-being, growth and development, socioecology, evolution, and conservation of several species of captive, wild, and fossil nonhuman primates, including chimpanzees, howler monkeys, spider monkeys, capuchin monkeys, galagos, and lemurs. Most recently she investigated the pet trade of lemurs in Madagascar with Dr. Kim Reuter. She has published extensively in her field with a particular focus on the primate pet trade.

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Salt Lake Community College

TRANSFORMING ORGANISATIONS WITH HONEST CONVERSATIONS

To face new challenges and societal changes, organisations must be able to adapt their practices swiftly and effectively. But all too often, efforts to change organisations fail to achieve the desired results. **Dr Michael Beer**, Professor Emeritus at Harvard Business School, devised a new approach to organisational change informed by his extensive experience as a researcher and management consultant. His approach centres on the development of honest, collective, and open conversations between senior management teams and key people below the top.

The Pressure to Adapt

Organisations are required to operate in increasingly complex landscapes, marked by rapid market changes, technological advances, socio-economic problems, and new global phenomena. This places them under significant pressure to redefine their very purpose and strategies, and then adapt how they are organised, managed, and led in the face of these changes.

Irrespective of whether they are large or small, private, government or not-for-profit, organisations must be able to adapt if they are to survive and thrive in our ever-changing global scene. In many cases, however, successfully implementing new strategies has proven to be extremely challenging, with disappointing results that have forced leaders out of companies and brought new leaders in.

Dr Michael Beer, Professor Emeritus at Harvard Business School, has been exploring effective ways to implement business strategies. Over many years as a researcher and management consultant, he observed that leaders who employ top-down change processes fail to develop adaptive high commitment, high-performance organisations.

'We know from experience and research that organisational change is difficult at best and efforts to change all facets of the organisation in concert often fail,' says Dr Beer. 'Changes in one facet of the complex social system may be made but they are not followed by others. Quick-fix changes in tangible practices are made but deeper intangible leadership, cultural and management issues are left unchanged. By some estimates, about 70% of efforts to change do not achieve intended change in the desired time frame or fail entirely.'

The Silent Killers of Learning and Change

Dr Beer and his colleague Dr Russell Eisenstat collaborated with a team of senior managers at 12 companies, and over three decades with hundreds of others, coaching them to lead the Strategic Fitness Process (SFP), an intervention they developed to enable honest conversations about the extent to which an organisation is effective in achieving its strategic goals and a healthy culture. This allowed them to identify six key barriers consistently reported (80–100% of the time) by key lower-level people. Senior managers were found to be not fully aware of, or avoidant in confronting and changing the following:

1. Unclear strategy, conflicting priorities or unclear values.
2. An ineffective senior team.
3. Poor coordination and collaboration across the value creation chain – functions, business units and/or regions.
4. Inadequate leadership development resulting in too few effective down-the line leaders required to lead change.
5. Insufficient honest conversations about the quality of the strategy and effectiveness of the organisation in implementing its strategies and cultural values.
6. A top-down or laissez leader incapable of turning these barriers into strong capabilities.

These deficiencies in organisational and leadership capabilities prevent organisations from learning and adapting in conditions of continuous change and uncertainty. Dr Beer calls these deeper factors 'silent killers' of learning and change. Just as hypertension and cholesterol are silent killers (i.e., causes of heart attacks), these six barriers cause ineffectiveness, unhealthy cultures and failures to perform. They threaten the capacity of the organisation to adapt to the continuously changing competitive and social environment. To overcome these barriers, senior management must first enable the truth to be spoken to those in power if they are to learn how the silent killers and other problems stand in the way of organisational performance and health.

'The underlying problem is that management drives change from the top,' says Dr Beer. 'These approaches to change may produce the wrong organisational solutions and fail to develop the trust and commitment of people at all levels required to produce changes in long-held assumptions and ways of doing things.'

'This occurs because the pressures to change and improve performance from multiple stakeholders are great and getting greater,' says Dr Beer. 'In response, managers choose quick fixes to tangible problems instead of taking the time to foster honest conversation about the intangible and hidden silent killers that are causing their organisation to be stuck in neutral, unable to change and improve its performance fast enough.' Yet, we have found that the truth can be learned and a plan for changes made in 6 to 8 weeks using SFP.

Encouraging Honest and Open Conversations

This spurred Dr Beer to create a new approach to organisational change that places a greater emphasis on honest communication and cooperation between employees at different levels of an organisation. 'My colleagues and I developed a quite different approach to change, and worked with hundreds of companies and organisations who were willing to apply our counter-intuitive and counter-conventional approach,' explains Dr Beer. 'Our approach goes against the prevailing instinct to drive change from the top – particularly when there is pressure to change. At its heart is an honest conversation between the senior team of the organisation that has set the direction and lower levels who know why the organisation is ineffective in achieving the goal that senior teams have set.'

The new theory of organisational change introduced by Dr Beer and his colleagues emphasises the need to create an open and receptive space where people can be completely honest, without being perceived negatively for it or facing undesired repercussions to their careers, while also enabling senior managers to listen non-defensively. These conversations must be public, meaning that employees at different levels should be told the truth about arising issues by senior management and how they are going to address these issues. This approach increases trust dramatically between top management and lower levels, fostering cooperation and increasing commitment to a common goal.

Silent killers are a syndrome. They are interdependent and mutually reinforcing which accounts for why it is difficult to change one without changing the others. As such, a systemic approach like SFP must be employed for changes to be sustainable.

Developing The Strategic Management Process

The SFP Process, developed by Dr Beer and Dr Eisenstat, make his theory actionable and easy to use in real-world settings when new strategies require changes in the organisation.

'Our normative and actionable theory of planned organisational change and development is based on fifty years of helping leaders and their senior team to lead change. Our counter-intuitive approach employs a nine-step process,' says Dr Beer. 'We had to do this because what we are asking leaders and members in the organisation to do is unnatural in everyday life, counter-intuitive and goes against human instincts to avoid dealing with potentially threatening issues that could cause defensiveness and anger by those in power.

The SFP is a strategic management and organisation development process that every organisation requires to stay healthy and effective but is rarely done. It starts with the senior team developing a clear and short statement of the strategic and cultural direction they would like to steer their organisation toward. A task force containing some of their most talented key people below the top level is then selected by them to interview around 100 key stakeholders inside and outside the boundaries of the organisation. This task force is trained to conduct confidential unstructured interviews about organisational strengths to be preserved and barriers to the effective execution of top management's aspirations. Interviews are very open, sometimes emotional (e.g., 'I have known about these problems, but this is the first time our leaders have asked to hear about them and change them'). Employee paper surveys that are typically employed by most organisations do not have this effect.

Themes developed by the task force are reported back to senior managers in a carefully structured meeting with guidelines that prevent defensiveness and blaming that derail honesty. Importantly, this process is structured to ensure the senior team listens and learns. Working alone, the senior team then develops an action plan designed to address the barriers reported by the task force. It is then communicated to the task force. Meeting alone, the task force critiques the plan and feeds back any concerns to the top team. Finally, the task force and senior team meet again to finalise the action plan. What senior teams heard from the task force – the good, bad, and sometimes ugly – and their action plan is communicated to the whole organisation to close the loop and build trust and commitment to change ('I am impressed by our leaders' courage to hear the truth, tell us what they heard and make changes').

Moving Towards Sustainable Organisational Transformations

Dr Beer and his colleagues have conducted several in-depth studies to evaluate the extent to which SFP enables change in effectiveness, trust, and commitment as well as performance. These studies found honest conversations to be powerful and effective because they make deep issues discussable and actionable. Furthermore, people are relieved that senior leaders have heard their concerns and are committed to changing. These positive results are, however, contingent on the values and authenticity of the leader. Those who embrace the practice of honest conversations with the intention to learn and make changes, and repeat the process over time, are able to create remarkable and sustainable change.

The implications for creating sustained organisational renewal over time are clear. A process for honest conversations guided by the principles underlying the SFP must be repeated periodically at the top and in multiple units of larger enterprises – the corporate, business, functional, regional and country units. Leaders of these units must be held accountable by their leaders for implementing periodic honest conversations and reporting what they learned, plan to change and have changed. This requires a board of directors that will hold the CEO accountable and a CEO who will hold leaders below the top to do the same. It also requires the replacement of leaders who are unable or unwilling to employ the discipline of a renewal process that adheres to the principles underlying SFP or SFP itself at all levels. This will build and sustain an adaptive, high commitment and high-performance enterprise.

Meet the researcher

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Dr Michael Beer is a Professor of Business Administration at Harvard Business School. He holds a BA in Psychology from Queens College, an MS in Organisational Psychology and Statistics from North Carolina State University, and a PhD in Organisational Psychology from Ohio State University. In addition to teaching classes at Harvard Business School, Dr Beer is Co-founder and Director of the management consulting company TruePoint Partners and the not-for-profit Higher Ambition Leadership Alliance. His recent research explores the factors that make organisations particularly effective, including business strategies, the work of senior team members, leadership, coordination and collaboration. He has published prolifically in peer-reviewed journals and has authored many books, the latest being 'Fit to Compete: Why Honest Conversations About Your Company's Capabilities Are the Key to a Winning Strategy', in 2020. Dr Beer has been the recipient of many awards, including the 2006 Harry and Miriam Levinson Award for Exceptional Contributions to Consulting Organizational Psychology by the American Psychological Foundation, and the 2006 Distinguished Scientist-Practitioner Award by the Academy of Management. In 2011, he was named one of the Top 100 Thought Leaders in Trustworthy Business Behaviours by Trust Across America.

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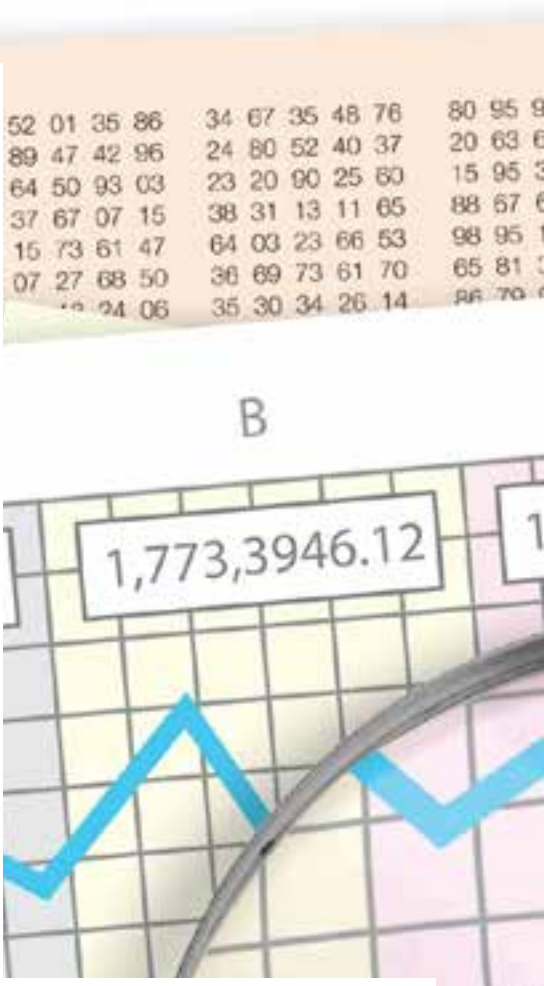
SKI ECONOMICS: USING DYNAMIC TICKET PRICING TO INCREASE SKI SLOPE REVENUES

The ski industry currently faces a number of challenges, including climate change, falling demand and lift ticket prices. **Dr Iveta Malasevska**, a senior researcher at Eastern Norway Research Institute based at Inland Norway University of Applied Sciences, is collaborating with colleagues on a project called 'Innovative Pricing Approaches in the Alpine Skiing Industry'. The team is examining pricing analytics at ski resorts in Norway intending to develop optimal pricing schemes to address the challenges faced by alpine ski resorts and improve their long-term financial performance.



Challenges Facing Ski Resorts

Norway is an alpine skiing paradise, as the season is long and many of the largest resorts are easily accessible from airports and ferry ports. In Norway, there are more than 200 ski resorts, and approximately 18% of these are located in Inland Norway (which since 2020, incorporates Hedmark and Oppland). In the 2021–22 season, there were almost 7.5 million visits to the Norwegian ski slopes (the latest statistics can be found here: https://alpinogfjell.no/fakta-og-statistikk).

Despite its popularity, the skiing industry faces many challenges that directly impact the profitability of ski resorts. These include shorter winters and the decline in natural snow cover (potentially due to climate change), as well as a global decline in the number of new active skiers, especially in younger populations.

There is also a hidden challenge to ski resort management relating to customer experience and satisfaction; customers assess service quality by comparing the service they receive with the service they expected to receive, and this determines whether they will return to the resort. However, many of the factors that affect this, such as weather conditions, are out outside of human control.

A consequence of these challenges is that the operational costs of running ski slopes are likely to increase as the resorts invest in advanced snow production and technologies. This may lead ski resorts to increase ticket prices to finance these investments, which in turn, can unintentionally deter customers from visiting the slopes, affecting the profitability of the resort in the longer term.

Dynamic Pricing Increases Profitability

These challenges are just as relevant internationally as they are to the Norwegian economy. For long-term survival, it is critical that ski resorts understand their customers' needs and

provide a value-for-money experience. Dr Iveta Malasevska of Inland Norway University of Applied Sciences, has determined that dynamic pricing is one key area where ski resorts can significantly increase revenues.

Several ski resorts in Switzerland and the USA have now implemented dynamic pricing. Such price differentiation essentially divides the market into segments, such that higher prices can be charged to those customers willing and able to pay more, whilst charging lower prices to those customers not willing to pay more.

This approach allows supply to be matched with demand, thereby selling more resort tickets and improving

company profitability. For example, airline companies use differential pricing, charging higher prices for business travellers and discounted prices for tourists, as well as increasing ticket prices in the weeks getting closer to the departure date.

An Introduction to the Project

Dr Malasevska is collaborating with colleagues on the 'Innovative Pricing Approaches in the Alpine Skiing Industry' (IPAASKI) project. The overall objective of this work is to follow up and extend the work of Dr Malasevska's doctoral research. As such, the team is examining and hopes to implement new pricing schemes to address the challenges faced by alpine ski resorts.

They have formulated several ambitious research questions, including how best the alpine industry could use new pricing schemes to attract new and young skiers, and how ski resorts could use pricing schemes to make skiing more environmentally sustainable.

A critical addition to the team's aims and objectives is to identify how effectively the ski resort managers can utilise their results and pricing recommendations. The need for more effective management of alpine ski resorts is essential to profitability, as visitor demand regularly fluctuates. For example, when the demand for alpine skiing is higher than the ski resort's capacity, the ski resort is losing out on potential visitors.

The Theory of Consumer Behaviour

The theoretical foundation for most of Dr Malasevska and her colleagues' work is the standard theory of consumer behaviour from economics. Here, it is assumed that consumers act rationally to maximise their utility, but that the expected utility may change according to different circumstances. For example, in the context of skiing experience, the length of queues and waiting times, the snow conditions at the resort, and the capacity of the ski lift, all indirectly and directly affect the skiing experience.

Most Norwegian ski resorts charge a constant price for various ski ticket passes over the entire winter season, but charge different prices for groups, children, adults and senior citizens. However, in today's constantly changing and open markets, this traditional pricing approach is no longer sufficient to ensure profitability. In particular, it ignores the customers' willingness to pay.

A Mixed-methods Approach to Allow In-depth Investigation

The project is now in the final stage and Dr Malasevska and the research team are hard at work conducting qualitative and quantitative analyses.

They began with a qualitative approach to obtain a deeper understanding of the prospects for dynamic pricing among managers and customers in alpine ski resorts. Having conducted in-depth interviews with both ski resort managers and alpine skiers, the insights obtained from these analyses

will be used to design future questionnaires. The team will also continue to implement complex statistical techniques used in market research known as conjoint analysis and non-linear optimisation.

Conjoint analysis enables the team to forecast customer choices in a way that is very similar to the actual marketplace. For example, the team obtained 722 conjoint-based questionnaires from active skiers and potential skiers to understand the relative importance customers attach to attributes of the skiing experience (such as weather conditions and price). This provides a basis from which to calculate the utilities the skiers attach to these various attributes, and what prices the resort could charge to maximise revenue, on a windy versus sunny day for instance.

The researchers have also collected data from real purchasing behaviour from a pricing scheme that was trialled at one of the ski resorts collaborating with the team on this project. The results of this can then be compared to the teams' predicted purchasing behaviour, allowing substantial investigation of the willingness of customers to pay related to changes in a company's pricing strategy.

Training Managers on Pricing Analytics

Norwegian ski resorts vary a lot in size and also in terms of customers' experience at the resort. This makes dynamic pricing a risky approach as revenues could collapse if large numbers of customers with a high willingness-to-pay switch to lower-priced offers.

Although ski resorts have control over internal characteristics, such as lift speed, snowmaking possibilities, and variety of ski slopes, the skiing experience is also affected by external factors that are not directly controlled by the ski resorts, as described above.

Dr Malasevska and her colleagues found that if the midweek weather conditions are noticeably better than those forecast for the weekend, customers tend to visit the resort on midweek days instead, despite a higher price. Awareness of such a customer reaction allows ski resorts to use a dynamic-pricing approach to shift demand away from more desirable periods to less desirable periods, and thereby reach a new group of potential skiers.

However, the team identified that resort pricing can be inefficient when managers lack expertise in pricing analytics. Taking this forward, the team have already conducted several workshops in which they presented the key findings from the project and discussed them with ski resort managers about how they could be implemented into practice.

Onwards and Upwards!

Both industry and academic experts have already expressed considerable interest in the results of the project. The team are developing recommendations for future research and their work will undoubtedly play a key role in helping alpine ski resorts confront the pressing challenges of our times and become financially more stable.

Meet the researcher

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Dr Iveta Malasevska was awarded her PhD in 'Innovation in Services in the Public and Private Sectors' from the Inland Norway University of Applied Sciences in 2017. She also holds a Masters degree in Business Administration and Management from the BA School of Business and Finance in Latvia. Dr Malasevska's fields of interest include business forecasting, revenue optimisation, value-based pricing, consumer behaviour, and tourism in general. Dr Malasevska is currently working on projects within tourism and experience economics, including the project 'Innovative Pricing Approaches in the Alpine Skiing Industry', funded by Regional Research Funds in Norway. She is a senior researcher at the Eastern Norway Research Institute based at the Inland Norway University of Applied Sciences, and her research has been published in respected journals including the Tourism Management, Tourism Economics, Scandinavian Journal of Hospitality and Tourism, and the Journal of Outdoor Recreation and Tourism.

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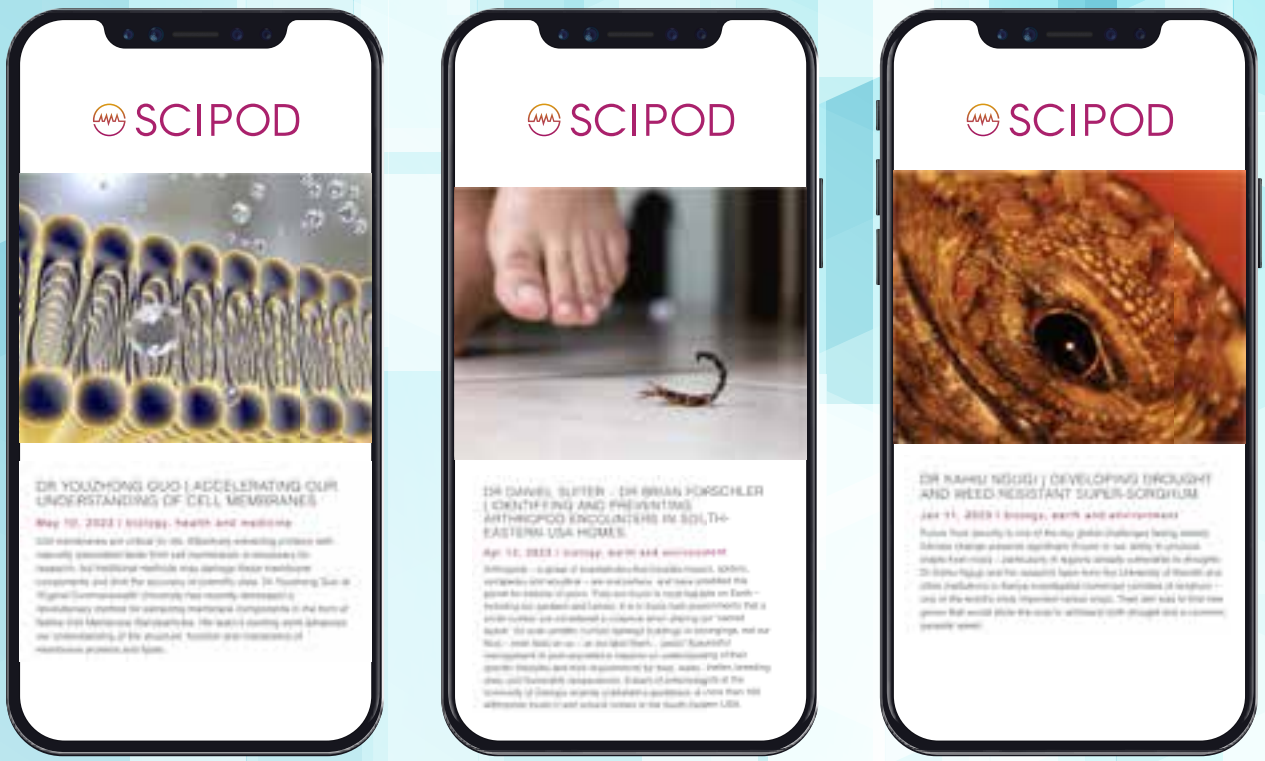

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