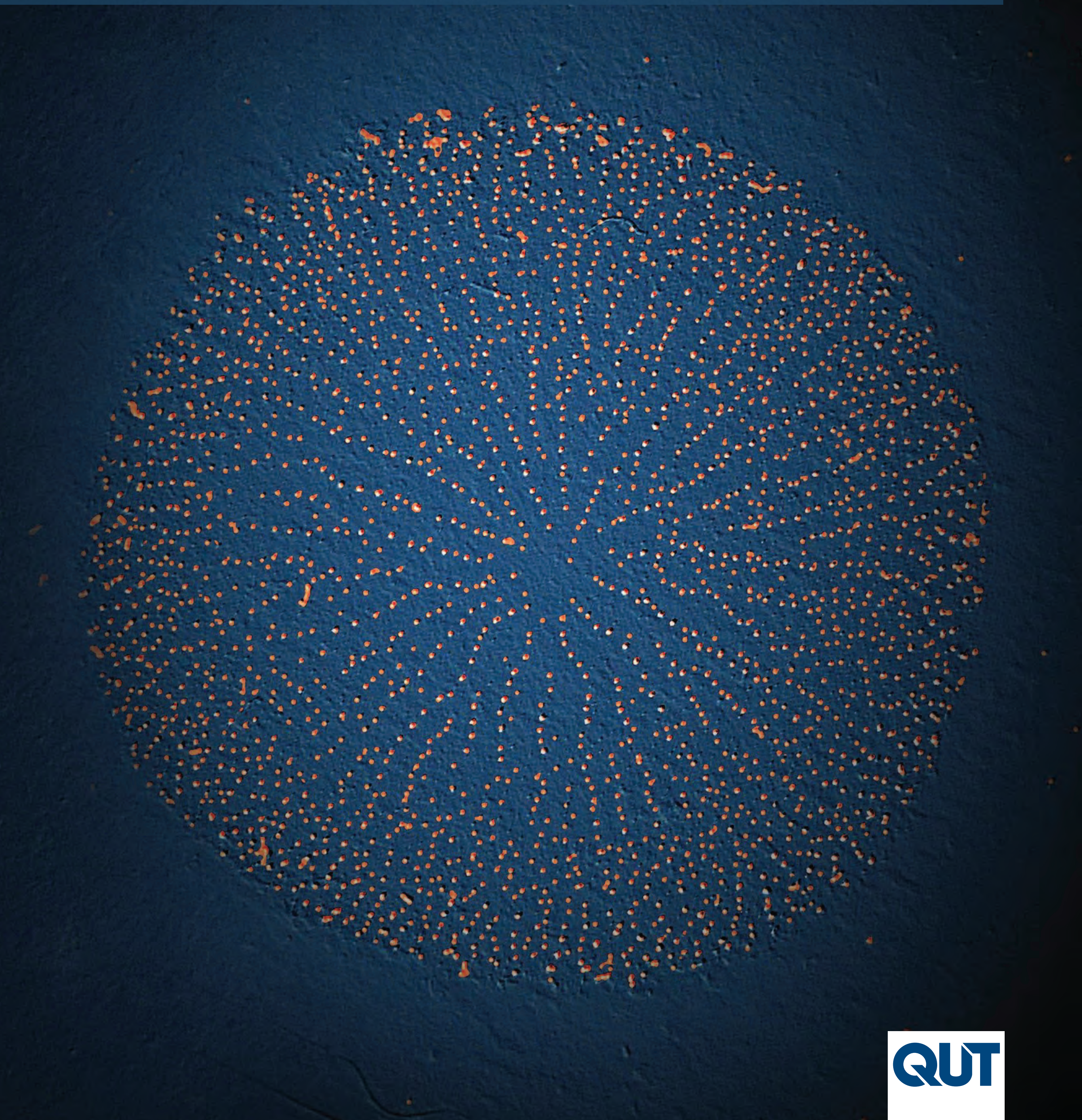
LEARNING AND
BIG SOLUTIONS (LABS)

THE LABS

2020



the university for the real world®

The QUT community acknowledges that our university stands on Aboriginal lands, the country of the Turrbal and Yugara people, lands that were never ceded.

We pay our respects to their Elders—past, present and emerging—and thank them for their wisdom, forbearance and spirit of sharing. We respectfully recognise the role that Aboriginal and Torres Strait Islander people play within the university and in the wider community. We celebrate that the lands on which we study and work have always been places of learning, research and engagement.

ABOUT THE LABS

The LABS is an annual snapshot of QUT science and engineering research and learning.

In 2020, we feature stories from the newly formed QUT Centre for Data Science, QUT Centre for Materials Science and the QUT Centre for Robotics.

QUT research centres represent high-quality and focused research activity aligned with the university's key strengths. These innovation hubs encourage research leadership, and support the growth and sustainability of future investment.

These and other research centres were established with the primary purpose of developing high-quality research outcomes in capabilities that make a real difference in Australia and around the world.

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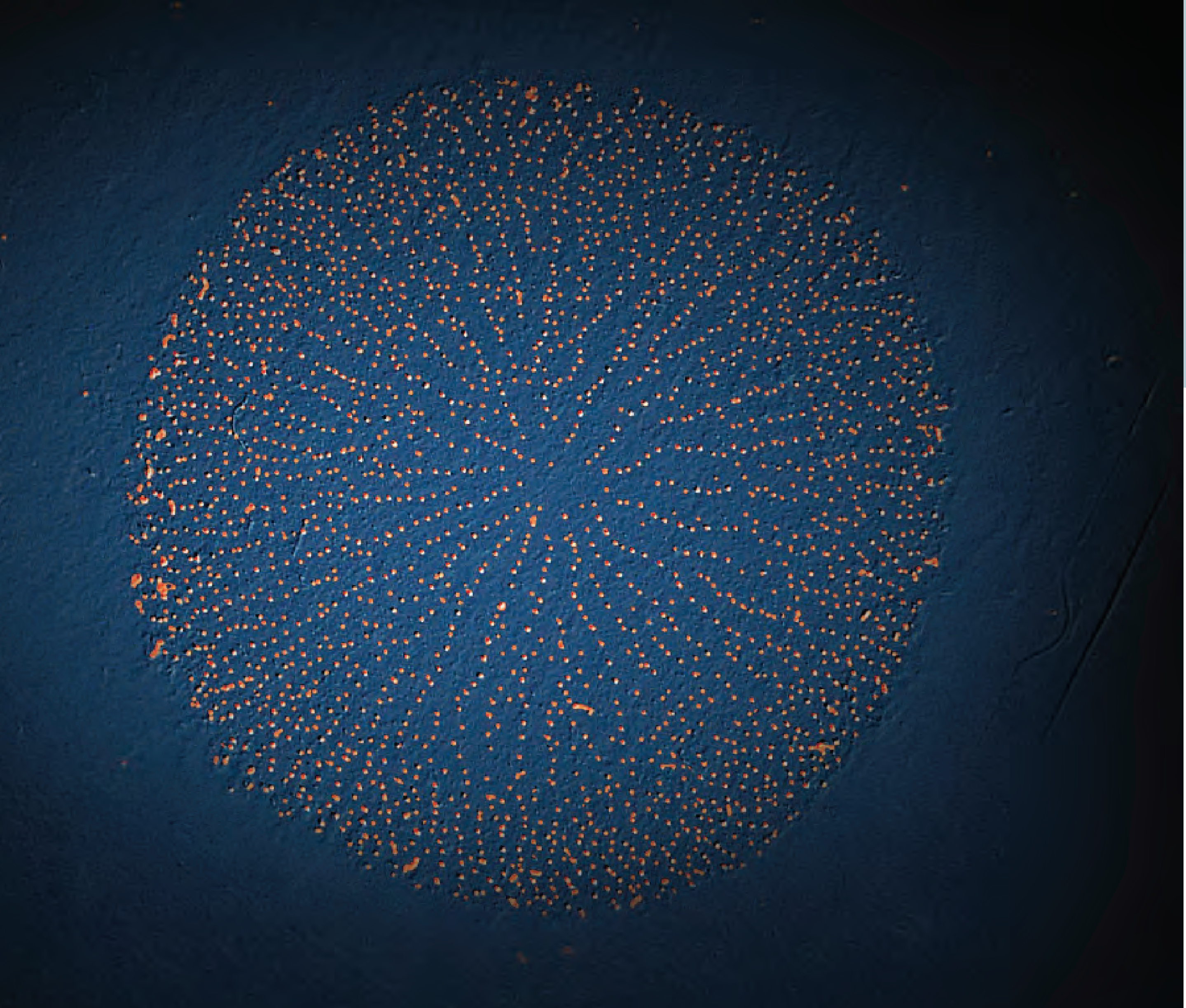

COVER IMAGE

Hydrophobic gold was taken by Associate Professor Eric Waclawik from the QUT Centre for Materials Science for the 2020 QUT Science in Focus competition. The annual competition offers insight into the unique research processes and objects used by QUT researchers in their pursuit of new knowledge.

ARTIST'S DESCRIPTION

Hydrophobic gold is a snapshot of the spontaneous aggregation of hydrophobic gold nanoparticles into an organised pattern, floating over a hydrogen peroxide ocean. The dynamic growth of these gold nanoparticle-aggregates from a seamless monolayer is produced after a droplet of the volatile solvent medium containing gold precursor seeds oscillates in space and time while evaporating at room temperature, leaving behind the pattern of gold.

This research into nanoparticle monolayer films is preliminary work investigating active nanoparticle systems that cluster and dissolve when exposed to different external stimuli. Encoding motion into self-propelled systems like this could have many new applications, including transporting small particles or molecules to a target location, following a given trajectory, mimicking simple forms of replication or basic gradient-sensing.

FOREWORD:
Collaboration through dynamic and challenging global change

Professor Troy Farrell
Executive Dean

I am delighted to share our recent highlights in this latest edition of The Learning and Big Solutions (LABS) snapshot.

Recent events have led us to make rapid changes in how we work and collaborate, while remaining steadfast in our vision to be the partner of choice for science, technology, engineering and mathematics (STEM) education and research.

As with many organisations, the global health crisis has brought sharply into focus our inherent capacity as a community to innovate and adapt to change. We are very grateful to all our valued partners who worked with us throughout this challenging but dynamic period to deliver some of our most impactful outcomes yet.

Among many such initiatives, our researchers designed a ventilator to improve COVID-19 patient treatments, developed a breathable mask material effective at removing virus particles, and studied virus behaviour to provide critical insights into its aerosol transmission.

Our newly established research centres are also working collaboratively with industry to develop world-leading applications in a range of sectors including defence, aviation, manufacturing, agriculture, textiles, health and more. These centres bring together our internationally recognised expertise to develop real-world solutions in areas such as data science, novel materials and robotics.

We have centred our priorities around the online delivery of courses and are expanding our digital learning capabilities to deliver high-value STEM education in both virtual and on-campus settings. Importantly, our industry partners have remained key enablers of practical student experiences through our work-integrated learning program—the cornerstone of QUT's commitment to graduate outcomes and opportunity. Even during periods of heightened restrictions, ongoing support from our partners has provided unique professional experiences and prepared students for a future workforce where people work together remotely.

In response to growing demand for STEM capabilities across many sectors, we have created graduate certificates in IT and data analytics, as well as new vertical double degrees coupling biomedical sciences and education with our Master of Data Analytics. We will also add to our fully online offerings in 2021, with online undergraduate degrees in IT and data science. As always, we continue to engage with our stakeholders to meet changing industry needs and find new ways of increasing our collaborative outcomes.

Thank you for your support and I hope you enjoy these snapshots into the many ways we are growing and innovating the global STEM research and education space.

THE LABS 2020

DATA SCIENCE

QUT Centre for Data Science

Building an understanding of society, technology and the environment with statistics-led and machine-based data solutions.

LEFT AND ABOVE Artist's impression of Queen's Wharf development. Source: Destination Brisbane Consortium. Concept image only, subject to approval.

DATA AND THE CITY: Tracking growth and change for Queen's Wharf

KEY CONTACT Distinguished Professor Kerrie Mengersen
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The Brisbane city skyline is changing. Queen's Wharf Brisbane is a $3.6b integrated resort development being built along the river in the city's CBD. The new precinct will include hotels and residential accommodation, a casino, retail and entertainment areas, and new public spaces.

Understanding how the Queen's Wharf development will impact the city and its population is key for creating sustainable, impactful infrastructure works now and in the future.

The Queen's Wharf Longitudinal Benefits and Impacts Study, jointly initiated by QUT and the Queensland Government, is the first longitudinal study of a major infrastructure project—and its findings will change the way we look at our city's data.

A changing city

Queen's Wharf Brisbane is the development of a generation for Brisbane, and it promises to deliver significant benefits and impacts for the city, regional areas and Queensland. Those benefits and impacts need to be captured, measured and analysed.

Led by a team of researchers at QUT's Centre for Data Science, the multi-phase study is measuring benefits and impacts across 22 areas of public life.

The most recent phase of the study has focused on public attitudes towards Queen's Wharf Brisbane across several key areas: gambling, connectivity (how people move into, out of and around the precinct), finance and construction, safety, economic growth and tourism.

ABOVE AND BELOW Artist's impression of Queen's Wharf development. Source: Destination Brisbane Consortium. Concept image only, subject to approval.

Data will be compared with available statistics from similar developments in other states, such as Melbourne's Crown Casino, for further benchmarking.

Looking at data gathered over a long time frame gives unique insight and allows researchers to measure change against clear benchmarks.

Distinguished Professor Kerrie Mengersen, chief investigator at the Centre for Data Science, has been instrumental in establishing data collection and interpretation for the study.

"Now that we've established a baseline, we can begin tracking changes in those key areas as construction moves forward and Queen's Wharf beings to take shape," Mengersen said.

The study won't stop once construction workers down tools.

"We'll continue capturing data and providing key insights about the development ahead of its opening in late 2022 and extending 20 years into the future," Mengersen said.

"The data we provide—and the learnings we take from it—will inform government and the community, and shape our public spaces for years to come."

"The dashboard we've developed will allow policy makers in the government to explore the data and see the impact of Queen's Wharf Brisbane as it happens.

We're also aiming to make the dashboard available to the public so they can be more engaged with how their city is changing."

DISTINGUISHED PROFESSOR KERRIE MENGERSEN

Forward-thinking data studies

Collecting and interpreting data of this scale for a project of this magnitude required a specific study design that could capture the impact of Queen's Wharf meaningfully and accurately.

"If we just ran the project over a few months, we could get a snapshot of the economic and social profile of Brisbane, but we wouldn't know how that changes over time," Mengersen explained.

"A longitudinal study can show us how that profile changes as the development is opened and as it matures, giving us a much longer-term view of the impacts."

In this longitudinal study, the team at the Centre for Data Science have been collecting data since 2018, and will continue to gather and analyse data for years to come.

"Previous projects of this magnitude have relied on retrospective data to benchmark their measurements, if that data's even available. Otherwise they have to rely on memory," Mengersen said.

"That's what makes our study so ground-breaking for this field: we're collecting data from the start, so we can have a true understanding of impact across dozens of areas."

The first two phases of the study focused on fine-tuning the areas of focus for data collection and analysis.

An interactive dashboard is a key output of the latest phase of this project.

"The dashboard we've developed will allow policy makers in the government to explore the data and see the impact of Queen's Wharf Brisbane as it happens," Mengersen said.

ABOVE Artist's impression of Queen's Wharf development. Source: Destination Brisbane Consortium. Concept image only, subject to approval.

"We're also aiming to make the dashboard available to the public so they can be more engaged with how their city is changing."

The data gathered for the study comes from a range of sources including mobile phones, data repositories with the Queensland Government, and the Australian Bureau of Statistics.

"There's a lot more data that's being made publicly available these days from private and government sources, so the time is right to be setting up projects to look at the implications of these activities now and into the future," Mengersen said.

"We need that data to make decisions based on something real, not just by the loudest voice. We want decisions to be balanced and evidence-based."

The right experts

The team at the Centre for Data Science drew on deep domain expertise from across QUT to make the project a success.

QUT's Dr Char-lee Moyle is a management expert and provided key input on tourism and business impacts to establish a benchmark for future data analysis.

Moyle gathered data from a diverse range of sources, including visitor data from Tourism Research Australia, Telstra data to look at flows and patterns of human movement, business count data to understand the commercial makeup and function of Brisbane's CBD.

"A study like this one shows us just how extensive the wealth of available data is. The question now is how we can interpret it, access it, and work with it to show causation and better understand the impact of Queen's Wharf," Moyle said.

"The long-term effects of a project like Queen's Wharf will be remarkable—we'll see more tourism, more diverse and dynamic businesses, and a more vibrant city precinct thanks to residential and hotel space.

"It's important that we understand the impact of that growth, and the attitudes that future potential visitors have towards our city."

Combining an understanding of public perception with quantitative data on tourism rates and connectivity provides a deeper, more comprehensive understanding of the real impact of developments like Queen's Wharf.

Associate Professor Amanda Beatson specialises in public perception and social impact, and analysed public sentiment towards the development in its early stages.

"We listened to the chatter on social media, scraping any text published in the public domain online across different platforms, including news media," Beatson said.

"A lot of the early commentary focused on the disruption to commuters in the CBD, but that's changing as the population can start to see the development take shape.

"We can see public perception shift as people see the benefit for Brisbane, including potential employment, increased tourism, and how this development will put Brisbane on the map."

Through text scraping and active population surveys, Beatson measured public sentiment in the Brisbane CBD, the greater Brisbane area and Queensland more broadly.

"Social media demonstrates very strong opinions—both positive and negative—about any infrastructure project. Influencers on social media may sway others through social desirability, which is the need to be seen to share certain opinions to match what others are saying," Beatson said.

"We combined this data with surveys, which can give a more independent response, and can show scale of opinion from strong agreement to strong disagreement.

"Combining both approaches complemented the data analysis, giving it depth and balance, and helped us provide a more realistic interpretation of public sentiment.

"You have to know what people think about your development, because the consumer's voice is fundamental to how you're accepted out there in the public domain."

Beatson would like to expand the study into the future and revisit metrics to see how sentiment has changed over time, particularly once the development is finished and the public can access the space.

"We're supporting a new generation of data scientists with real-world training, who will be experienced in working with government and business to extract insights and make data-based decisions."

DISTINGUISHED PROFESSOR KERRIE MENGERSEN

BELOW Work under way at the Queen's Wharf development site. Source: Queensland Department of Innovation and Tourism Industry Development.

ABOVE AND RIGHT Artist's impression of Queen's Wharf development. Source: Destination Brisbane Consortium. Concept image only, subject to approval.

Why QUT?

QUT is a university that excels at real-world application of frontier technologies and couples this with leading academics in health, transport, big data, business and creative disciplines.

Our research has helped hundreds of organisations, industries and government bodies achieve their goals.

As the university for the real world, our research is user-inspired with an applied focus, and aligned to the human capital and innovation needs of the economy.

QUT's unique ability to assemble effective interdisciplinary teams ensures the depth and breadth of knowledge that the study requires, underpinned by innovative and emerging methods and technologies, research data, and databases.

The Centre for Data Science is home to the university's top data specialists and statisticians. Their transdisciplinary reach helped get the right experts in the right place to contribute to the study.

"We've brought people together from all across the university to work on this," Mengersen said.

"We've got specialists from engineering, mathematical science and statistics, health, business and digital media bringing valuable expertise, meaning we get the best possible interpretations of our data."

Working with government

The Queensland Government came to QUT in 2018 with the vision of a long-term study.

"They wanted a university to be involved to carry it forward, give it a long life, and have the independent and rigorous management that the project needs," Mengersen said.

Mengersen spent months embedded with the Queensland Government, learning about their needs, operations and capabilities.

"By working alongside the department's team, we began to build our study structure in a way that would ensure its success into the future," Mengersen said.

For the Queensland Government, the investment in QUT's expertise means the data capture and reporting meets the high standards required for a public infrastructure project.

"QUT established clear study principles and structure, which streamlines its processes and ensures its long-term viability," said Paul Krautz, the project's executive director at the Queensland Government.

"Having access to their interdisciplinary research team means our data is both accessible and analysed from multiple angles.

"We can also tap into that expertise and broaden the key study metrics to make sure we're looking at the benefits and impacts of the Queen's Wharf development as holistically as possible."

Next-generation data analysis

The study has recently attracted funding to invite an additional six PhD students to contribute to the research.

The Centre for Data Science is committed to fostering emerging research talent and promoting a culture of collaborative research training, from PhD students to early career researchers and beyond.

"We're supporting a new generation of data scientists with real-world training, who will be experienced in working with government and business to extract insights and make data-based decisions," Mengersen said.

"It's an excellent example of university researchers, government and business coming together to realise a long-term vision, and we're excited to extend this research well into the future.

"The next phase of this project will create opportunities for students and early career researchers to engage with external organisations and build their professional networks.

"We're building a constellation of postgraduate research opportunities, supported by co-funded PhD scholarships offered through industry collaborators."

In the upcoming phases of the project, Mengersen wants to invite more stakeholders to be involved in the process, providing key data and learning from emerging insights.

"We'd like to see other tourism boards and the Brisbane Airport Corporation get involved in the conversation and invest in this project's future," Mengersen said.

"If we continue to broaden the measures that we're monitoring over time, we can continue to uncover that bigger picture of Queen's Wharf Brisbane's impact.

"Although we're tracking advancements and impacts across so many key fields, there's always more to explore."

While this is the first time a longitudinal study has been developed for a major infrastructure project, QUT's Centre for Data Science believes it won't be the last.

Future projects that could follow in Queen's Wharf Brisbane's footsteps include major urban developments, new stadiums and large-scale events like Olympic games.

"This kind of project can be run on similar large-scale infrastructure projects with state and local governments," Mengersen said.

"It's vital that government and the public measure and understand the impacts these kinds of investments have on society and the economy."

MEET THE RESEARCHER: Text-based data, machine learning and creating change

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Associate Professor Richi Nayak is dedicated to data and data-led outcomes.

Specifically, her research focuses on analysing text data through data mining and machine learning, and developing algorithms to explore large repositories of text-based data to identify insights and trends, create profiles and generate reports.

The applications for this kind of research are endless. Nayak has worked across domains from agriculture to energy, health to transport infrastructure, marketing to online dating, providing bespoke advanced machine learning techniques for clients who need to understand their user base.

Straight from the source

Sources for text-based data analysis are varied, and the algorithms Nayak develops adapt to suit the input: scanning vast quantities of online information to compile reports based on published papers; scraping millions of social media posts; or analysing thousands of digitised documents saved from a dusty box in a government storage room.

From the data, these algorithms identify trends, patterns and features that can then be analysed further, or can be used to influence policy and change at organisational or institutional levels.

"There's an abundance of data available, and you'd struggle to make sense of it on an individual level, like a single tweet or an individual news story," Nayak said.

"We collect social media data and engage in a process called topic modelling, or clustering, where we identify users who talk about the same subject or theme. We can then look at influential users within those communities, look at the attitudes in those communities, and any hierarchies within the subgroup.

"From that, we can build a more complete profile of attitudes and contexts within the social media landscape, which clients can then act on in a much more informed way."

The data that is fed into the machine learning algorithms is key to producing a successful model. For text-based analysis this data takes on an additional layer of complexity as the analysis goes beyond occurrences and into semantics: words have meaning, and the machine needs to have an understanding of how language works.

> "As data scientists, we want to identify trends, validate our models, and produce something that's clear and intelligible for our industry partners. But I'm also inspired to have an impact and make changes in society through my work."
>
> ASSOCIATE PROFESSOR RICHI NAYAK

"The machine doesn't know that words are correlated in any way, so it needs to learn that before it can show thematic trends it comes across in the data," Nayak said.

"Right now my research is focused on developing ways to help the machine understand the inherent nature of the data—what its original context is, and what the shape of that is, so that it can build a base of understanding."

The shape of data to come

The idea that data has a distribution and a shape is key to understanding computational geometry, a central area of Nayak's research.

"Think of each word in a collection of text as a data point: some of those data points appear together more frequently than others in language," Nayak explained.

"For example, when 'machine' and 'learning' appear together, the meaning of the phrase 'machine learning' is different from the individual words when they appear independently.

"Within the text that's being searched—the search space—the machine can measure the distance between those data points to build an understanding of correlation, creating a geometric 'map' of the data.

"The sheer volume of data we work with means that it's too complex to incorporate into a real-world, visual medium, so the geometric shape is just defined by code and used internally by the algorithm.

"A sound machine learning algorithm can identify those correlations accurately and build a basic level of semantic understanding, and from there identify common trends, themes and profiles within the data sets."

These maps, called graph maps, can be visualised as a series of nodes with links between them—or, for a simplified version, as a word cloud.

"This is one simple method of showing quantitative text data in a way that's easy for everyone to visualise and understand," Nayak said.

For the majority of Nayak's work, though, the algorithms she creates are incredibly complex, capable of parsing billions of tweets to develop meaning.

"This means that based on words' occurrences and their context, a deep learning method can build a text classifier to identify, for example, a misogynist Tweet.

"That complexity of data can tell us amazing stories—the information is out there, and the programs we develop give us a way to understand it."

Inspired to create change

Although the application of data science can creep towards anthropology, Nayak's domain is firmly rooted in data collection, analysis and validation.

"As data scientists, we want to identify trends, validate our models, and produce something that's clear and intelligible for our industry partners, while social scientists want to understand the demographic drivers beneath the data," Nayak said.

"That said, I'm inspired to have an impact and make changes in society through my work.

"Many of my projects are applied research to solve an industry problem or provide insight to a sociological issue, so I get to see the data analysis translate to real outcomes that affect real people."

MARKETING MADE EASY: Using machine learning to create marketing solutions

KEY CONTACT

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The future of marketing is robotic. Associate Professor Richi Nayak, a program leader with QUT's Centre for Data Science, has combined artificial intelligence (AI), machine learning and big data to develop a prototype of a data-driven marketing platform called Robotic Marketer.

"The platform will revolutionise the way companies look at developing marketing plans and strategies," Nayak said.

"Robotic Marketer empowers companies to quickly generate a strategy instead of spending hours of manual effort."

A sophisticated system

Nayak and her team worked with Australian company Marketing Eye to design and develop a platform that recommends purpose-driven marketing activities based on past report analyses, and company and competitor profiles.

"Robotic Marketer is the first integrated one-stop system that can recommend strategies based on input from a client," Nayak said.

"Existing systems are limited in their functionality and can only help the client with part of their strategy development.

"We wanted to create a platform that could automatically recommend more holistic marketing actions. For example, how a company can increase its social media profile on specific platforms, identify relevant events, or find trade shows and publications that can be targeted for advertising."

Nayak developed a novel system of automated task allocation within Robotic Marketer's server to streamline the information-gathering process, allowing the platform to complete multiple simultaneous requests and retrieve large amounts of data, which it then translates into consumer-friendly output.

"As a system, it's sophisticated enough to cover all bases, including automatic competitor identification, search engine optimisation, marketing strategy report generation, and adapting to changed market scenarios," Nayak said.

"What used to take an individual marketing professional 40 hours to complete can now be done in 7 hours.

"Robotic Marketer takes around 3 hours to generate the strategies automatically, plus an additional 4 hours of editing and consulting as a marketing professional finalises the output strategy report."

Globally aligned, robust and scalable

For Marketing Eye, the prototype has opened doors to a world of possibilities for their business.

"QUT was able to expertly bring together all facets of the marketing mix," said Mellissah Smith, founder of Marketing Eye.

"They've combined machine learning, AI and data in new and exciting ways. We haven't seen this before in marketing strategy development, and we're excited to see how it can improve our business model."

Robotic Marketer is designed to be easy for clients to use, while still housing a powerful machine-learning system in the back end. Streamlined functionality between front-end and back-end data repositories mean that accessing output is simple for non-technical users.

"The Robotic Marketer prototype was pivotal in getting the company where it is today," Smith said.

"We've now built an enterprise-level automated marketing strategy technology platform. The system is globally aligned, robust and scalable, thanks to the obstacles the QUT team pushed through during early production."

Nayak sees this technology as vital for the future of marketing practice.

"More than 70 per cent of marketing functions will be automated by 2030. We already see this in social media, content management, marketing automation and customer relationship management," Nayak said.

"With further advancements in deep learning technology, more AI systems like Robotic Marketer will emerge across the industry."

> "The platform will revolutionise the way companies look at developing marketing plans and strategies.
> Robotic Marketer empowers companies to quickly generate a strategy instead of spending hours of manual effort."
>
> ASSOCIATE PROFESSOR RICHI NAYAK

PROTECTING OUR WONDERS: Better reef monitoring through simulation

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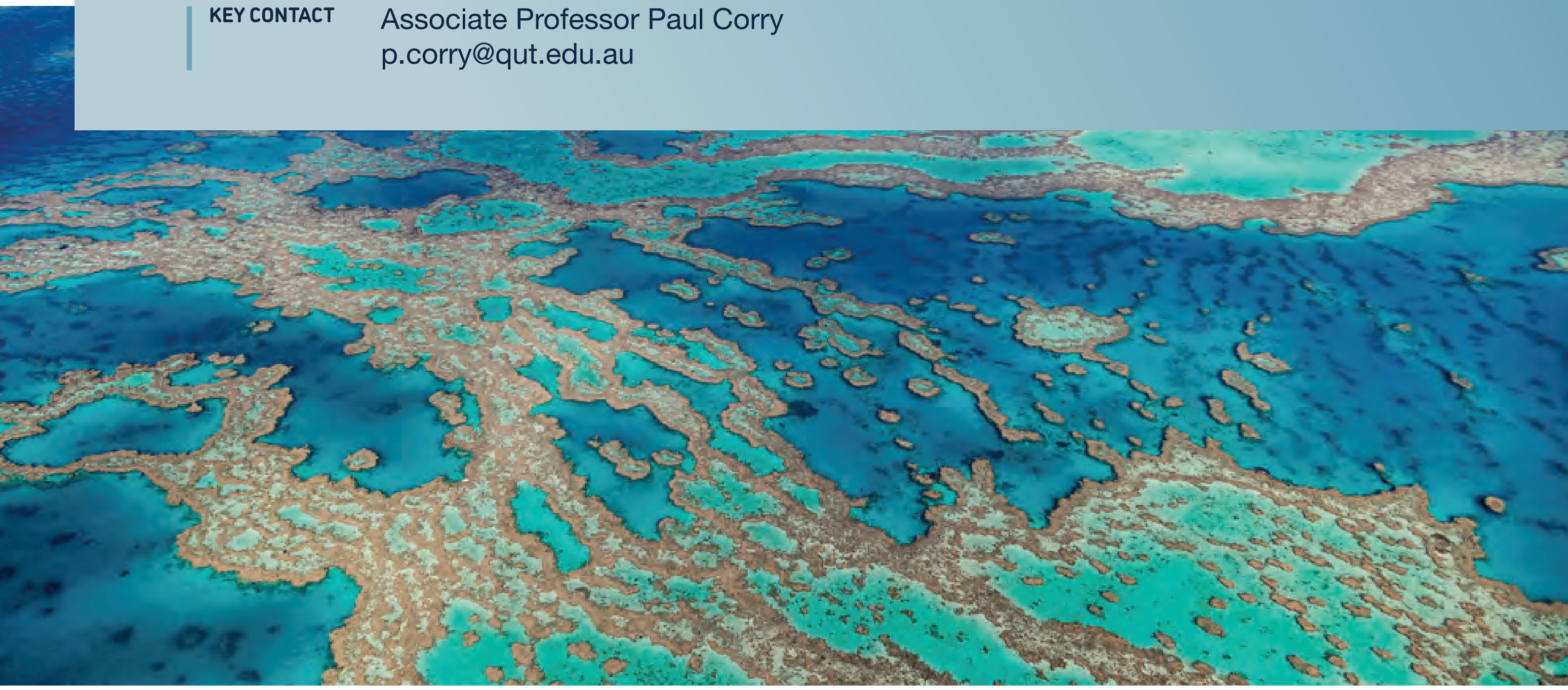

Researchers at the QUT Centre for Data Science are working with the Australian Institute of Marine Science (AIMS) to optimise reef monitoring processes and improve asset management.

Associate Professor Paul Corry is developing a data-based simulation that will model reef monitoring operations. Scientists at AIMS will be able to explore how changing their monitoring schedule and adopting new technologies can impact their efficiency on the water—all with the click of a button.

A model to optimise resources

The model is built on the back of data gleaned from GPS tracking from AIMS's fleet of monitoring vessels, giving accurate information on the geographical parameters of monitoring operations including the sequences of reef visits and travel times between them.

Corry and his team combined this with data from AIMS scientists to map the entire process of human and equipment interactions on a monitoring mission, and model the timing and dependence of sequential and parallel actions.

"There are a lot of challenges in simulating an operation like this," Corry said.

"Monitoring involves visiting multiple reefs and undertaking multiple sampling methods over the course of one or two weeks, so there are a lot of elements at play.

"There are constraints around when crews can work, when they need to take breaks, how limited resources can be shared between teams, and when vessels may not be able to move between locations due to tides, weather or other factors."

The model will allow the team at AIMS to input different scenarios and model combinations of staffing, technologies, vessels and routes to understand what limits the current methods and what types of approaches can optimise their resources.

"Say there are two vessels with different capabilities and a range of reefs that need to be monitored—the team needs to decide how many staff should be on each vessel, and how many reefs each vessel will visit," Corry explained.

"They can plug that information into the model and it will predict the timing for the whole operation.

"From there, they can understand the limitations of their current methodologies. They can see how investing in new technologies, resources and infrastructure can allow them to scale the monitoring operations to efficiently meet the needs of a changing environment."

The model also draws on historical weather data, which will make the simulation able to quantify uncertainty in the face of potential adverse weather events.

"You never know what mother nature is going to throw at us, and that can hamper accuracy and cause random disruptions in operations," Corry said.

"Building that weather data into our model gives a more accurate prediction of the possible range in mission timing to a 95 per cent level of confidence."

QUT has a long-standing partnership with AIMS, providing tailored solutions to their specific industry issues.

This six-month project builds on initial work that AIMS staff produced, bringing the technical expertise needed to boost their simulation and bring the project to fruition.

"The fact that AIMS took the initiative and started developing the simulation themselves gave us a great foundation to build on," Corry said.

"The team at AIMS understands the complexities of the model and the types of data needed to support it, so they were well prepared to see the project through to development."

Efficient, interactive and immediate

The project will improve operations for AIMS and the reef in multiple ways.

"We'll save a lot of time in the planning process, as we're replacing a labour-intensive, tedious number-crunching task with a streamlined computer program," Corry said.

"The model also allows AIMS to try out more scenarios and alternative monitoring plans in simulation, which they can then refine and optimise to improve efficiency and make better use of their available resources."

The model is adaptable, so the team can easily simulate new processes or technologies to improve aspects of the operation, and assess the impact before making the financial investment.

"This ability to identify the best places to invest in people, resources and technology is a game changer in ensuring that AIMS has the capability it needs to meet future demands," Corry said.

"For example, the team might look at replacing a human diver with an autonomous system—while this may save money in the short term, it may be far less efficient than a skilled human, costing more time over longer periods."

Initially the model will simulate single missions, but with the right data can expand to a 12-month view, which will show the big impact small changes can have.

Researchers are also interested in using computational optimisation methods to further improve the model's capability.

> "By developing clever algorithms, we can program the model to run these what-if scenarios without human input, and try thousands of scenarios autonomously to find the optimal combination of resources and time," Corry said.

Improving processes for reef monitoring will have a lasting impact on reef health in the long term.

"The Great Barrier Reef alone covers an area the size of Italy, which is a lot bigger than people realise, and there's a lot of territory that the team at AIMS needs to cover for their monitoring and science programs," Corry said.

"It's impossible to cover the whole reef, but we can help them monitor as much as their assets and resources will allow."

BELOW AIMS vessels RV Solander and RV Cape Ferguson on the Great Barrier Reef. Source: Australian Institute of Marine Science (AIMS).

COMPETITIVE SWIMMING REIMAGINED: using data to help get the win

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Imagine this: It's the 2024 Olympic games, and the Australian swimming team is optimised to win—not just through dedicated training and exceptional skill, but algorithmic prediction models to refine the team's makeup into a composition with the best chance of getting the gold on the big day.

With sports becoming ever more competitive, a misstep could be the difference between gold and going home empty-handed. Data analytics and predictive models can assist coaches and athletes to better understand what is needed for a win, and help better prepare for elite competition.

Dr Paul Wu at QUT's Centre for Data Science is working alongside industry partners from Swimming Australia, the Australian Institute of Sport and the Queensland Academy of Sport to develop predictive models for relay team composition, qualifying swimming times and pacing.

New time trials

"Predicting winning times is a lot like goal setting—it's about understanding how fast you need to swim to achieve first place, or third place, or qualify for the Olympics or world championships," Wu explained.

A more traditional model might see coaches looking through recent elite swimming times as a guide and setting a goal to beat the previous year's record.

"Our model is more sophisticated, and is 19 per cent more accurate compared to just using the previous winning time as the standard to beat," Wu said.

The model can't tell a swimmer whether they'll win or not based on their swimming times, but instead works in the realm of probability.

"We build up a probabilistic model based on trends over time. This means we can predict not just winning times, but also estimate the probability of events such as new world records, or the probability a certain time has of winning," Wu said.

The accurate model has a mean error rate of 0.5 per cent: this means that if the winning time for a race is 100 seconds, the model's mean prediction will be within 0.5 seconds of the actual winning time on average.

"Trends over time have shown a steep decrease in winning times over the middle part of the twentieth century, before levelling out in recent decades as we inch toward the peak of human ability," Wu said.

"Once you can characterise the patterns of winning times, and especially the uncertainty and variation, you can get useful insights that allow for risk-informed ways to train and prepare athletes."

Fine-tuning the relay team

Choosing who makes the cut and how they are run in a relay race is a complex decision for coaches and national selectors—one with a lot of variables and potential outcomes.

"If you had the four top-ranked swimmers in the world on one team, you'd obviously put them in your relay team," Wu said.

"But that's rarely the case, so there are a lot of different variables and statistics to consider when looking at relay team make-up.

"Our machine learning models use real data from elite competitions to explore trends in relay team performance, which can then help predict the probability of different race outcomes depending on swimmer calibre and racing order."

Relay teams are usually made up of the four fastest swimmers in a country's roster; but beyond just speed, the order in which they swim has a significant impact on the potential to win a medal.

The analysis shows that teams typically have a better chance of winning a medal if the two fastest swimmers lead off the race or bookend the relay order. The model computes probabilities of winning gold, silver, bronze or no medal with different configurations of the team and their competitors.

Coaches can use the model to run different race scenarios and make risk-informed decisions. They can decide whether to take a chance, for example, on a more certain bronze medal, or to tweak the swimming order for a higher probability of getting silver even if it means the chance of not winning a medal at all may increase alongside it.

"It's about risk verses reward," Wu said.

"Is it worth risking a higher probability of not medalling in order to have a higher probability of a better medal? Or should you play it safe and aim for the bronze?

> "Our model can help coaches and decision makers virtually explore team selection and ordering strategies, and they can then trial these strategies in the water to see how their teams perform."

The next generation of solutions

Wu and his team worked with undergraduate mathematics students from QUT who were eager to explore research opportunities as part of Australian Research Council Centre of Excellence for Mathematical and Statistical Frontiers internships and QUT's Vacation Research Experience Scheme.

"The undergraduate students are always eager and learn quickly, and it's a great opportunity for them to see the impact of their work as it applies to end users," Wu said.

"When you work with industry, just being good at maths isn't enough—you have to be able to communicate, to be organised, and to create a human connection.

"That's the most valuable skill that these students can take out of a project like this: how to deal with industry partners, and how to put the things they learn into practice in a real environment."

MEET THE RESEARCHER:
Data by design

KEY CONTACT Professor James McGree
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Professor James McGree strives to make data collection more informative, cheaper and less time-consuming. By developing new statistical and computational methods, his research finds smarter ways to collect data, leading to better efficiency when answering research questions.

BELOW Professor James McGree.

Professor James McGree's work in experimental design crosses multiple disciplines, from health to reef protection to monitoring waterways, and he has helped partners in a wide range of industries.

"Anywhere I can apply new, emerging and advanced statistical methods to help answer pressing questions and have real-world impact—that's where I want to make a difference," McGree said.

More efficient data collection

Developing modern methods in experimental design means that McGree has been able to improve efficiency for high-volume data settings. When working with large-scale environmental systems, understanding when and where to collect data is key.

"Modern data science has presented new challenges to statisticians. It has forced us to extend and develop new methods to handle real-world problems in research and industry," McGree said.

"Datasets can be large, but you don't necessarily need a large dataset to answer your research question. Thinking about the data we collect from new angles means that we can develop new approaches to understanding that data."

This agility has led McGree to develop unique solutions for situations where datasets are hugely expensive to collect.

"Having limited opportunities to collect data can be quite challenging. If it's time sensitive or if there are financial pressures, it's even more important that we get it right the first time," McGree said.

"I always ask the partner or end user what their goal is, what success looks like for them. That really determines how we will analyse the data, and how we can target data collection to minimise uncertainty about the inferences drawn from it."

New frontiers in clinical trials

By developing adaptive trial methods, McGree is at the vanguard of exciting new advances in how statisticians develop and deliver clinical trials in health research.

"Clinical trials have been modernised through new statistical methods," McGree said.

"Traditional clinical trials are quite regimented and take more of a 'wait-and-see' approach. While there are advantages to this, adaptive trials can be more patient-centric, and often arrive at a statistically significant answer faster."

Traditional clinical trials usually involve giving half of the trial participants a treatment and the other half a placebo. At the conclusion of the trial, the results are compared and conclusions are drawn.

“With adaptive trials, you learn as you go. You start out allocating the placebo and active treatment with equal probability, but if the treatment looks promising, then new participants can have a higher chance of receiving it. While we learn, we’re also providing more participants with what we believe is the preferred treatment,” McGree said.

“It’s more agile. You can drop treatments that are underperforming, or even include a new treatment mid-trial.”

Because of this flexibility, adaptive trials can be considered more ethical than traditional trials, as it means trial participants who need treatments that work may get them faster.

“It’s really useful for tackling diseases or developing treatments where you need to move rapidly and there’s uncertainty around what will or won’t work, like with emerging infectious diseases. These adaptive trials are becoming quite sought-after,” McGree said.

“It’s just one of the many ways mathematics and statistics can have huge impacts on the world and how we live in it.”

Safer, healthier waterways

Working with core methods in data science means that McGree can adapt his methodologies and practices to other fields, including environmental monitoring.

McGree is working with the Gold Coast Waterways Authority (GCWA) to develop statistical methods to determine how the public use the area’s waterways, and how that might be impacted by weather, currents and tides.

Measuring and monitoring how public waterways are used is key to informing waterway management for environmental protection and resident safety.

“The outcomes will help inform new policies to protect the environment and look after the residents in the area,” McGree said.

“And, as an added bonus, we often get to venture out into the beautiful waterways of the Gold Coast region.”

GCWA have provided McGree and his team some interesting challenges to explore.

“They want to find out whether boat speed can be reliably estimated from land-based cameras,” McGree said.

“That’s quite difficult, because it’s very different to estimating the speed of your car, for example.

“You have to account for the current and other potential factors. Currently, land-based cameras can’t estimate boat speed precisely. We hope to provide a new solution here.”

McGree and his team have set up around 20 cameras along the waterways, which are taking photos every second. The cameras will be in place for at least 3 months collecting immense amounts of data about the quantity and frequency of boats and other vessels, and the pathways they take.

The team will then develop algorithms to turn these cameras into “smart cameras” that can automatically identify vessel type and estimate vessel speed.

Queensland Police Service will be helping the researchers collect vessel speed data. This will allow researchers to calibrate their algorithms and determine the accuracy of their predictions.

“This is an exciting proof of concept study,” McGree said.

“We’re not interested in developing anything that could potentially be enforceable, but we just want to see if it can be done.”

DATA-DRIVEN SOLUTIONS:
Predictive models for healthy waterways

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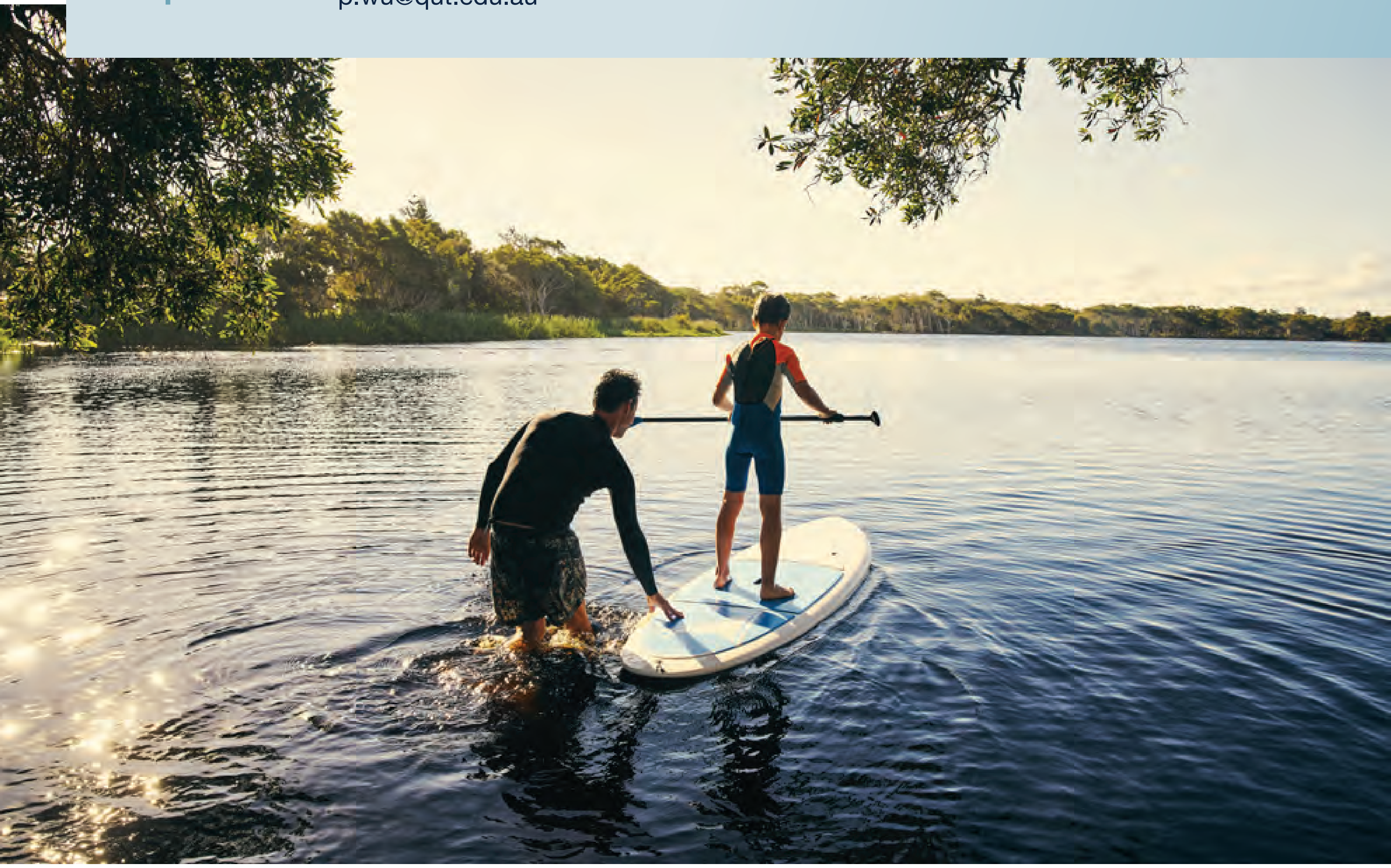

"More frequently than ever, our industry partners are asking for something that lets them be proactive rather than reactive. They want to see what data can tell them about future trends and probabilities so they can better manage resources."

DR PAUL WU

Improving the health and longevity of our waterways means cleaner drinking water, safer recreational spaces and healthier environments.

Dr Paul Wu and his team from the QUT Centre for Data Science have developed a data-driven dashboard for Healthy Land and Water, an independent organisation using science-based solutions to protect and enhance natural assets. The dashboard will help monitor and protect over one hundred fresh-water and salt-water sites across South-East Queensland.

In collaboration with microbiologists and environmental scientists at Healthy Land and Water, Wu has developed a predictive model that will help the organisation be smarter about how it manages its waterways.

A dashboard for decision makers

The dashboard is powered by data on rainfall, historical microbial bacterial levels and site characteristics to predict the risk of microbial contamination.

At the recommendation of microbiological experts, the model uses indicator bacteria *Enterococci* as a predictor of bacterial levels across the site.

The dashboard combines information across similar sites to maximise its power to predict, which then helps decision makers know when to conduct testing of waterways or if they may need to close a site. It can also help to manage risk associated with commercial use of waterways and large events.

"Having all of this information in one place means that Healthy Land and Water can act much faster to manage their sites," Wu said.

Enabling industry proactivity

Wu works exclusively with applied statistics to develop solutions for industry problems.

"More frequently than ever, our industry partners are asking for something that lets them be proactive rather than reactive," Wu said.

"They want to see what data can tell them about future trends and probabilities so they can better manage resources."

For water health management, changing to a predictive model is a big departure from traditional methods.

"In the past, monitoring water quality has involved taking samples and looking at them in a lab before making a decision. But that testing takes time," Wu said.

"If the waterway is still open to the public while the tests are being run, that's time when the population is potentially put at risk.

"Our model lets us look at the mitigating factors and know ahead of time if the risk is too high for people to safely access a body of water."

The dashboard has been specially designed with the end user in mind so that it's easy to use and interpret. Users can enter their own scenarios and get predictions about the probability of exceeding acceptable levels of microbial activity.

"Our client base is diverse, so we needed to make the dashboard intuitive, contextualised and interpretable," Wu said.

"We've worked with Healthy Land and Water representatives to iteratively develop a prototype that works for them."

As the Healthy Land and Water team add data, Wu's team will continue to refine and improve the dashboard, providing insight to healthier waterways into the future.

UNDERSTANDING THROUGH DATA

QUT Centre for Data Science

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Everything we see, touch and understand is data. By learning how to model, interpret and interact with that data, researchers can build models to predict our future.

The QUT Centre for Data Science is solving fundamental problems in gathering, modelling and analysing data to make data-informed decisions that deliver benefits to industry, society and the environment.

Our strong network of data science researchers is developing exciting and innovative solutions to industry's problems and building a national reputation as a results-focused research hub.

When you connect with the QUT Centre for Data Science, you're taking the first step on the road to innovation, discovery and opportunity.

Our research

Our applied domains bring together research experts from multiple fields to focus on a specialised problem. We're exploring the application of data science in:

- health and biological systems
- environment and natural systems
- business and engineering systems
- social systems.

Data for discovery

Our research is advancing the medical, physical, technological and social sciences by developing and applying new statistical, analytical and computational methods. Data acquisition, transformation and analytics, alongside experimental design, become the locus of new and evolved thinking.

Novel modelling and algorithms

As our knowledge grows, so too do the tools with which we explore it. By developing new computational algorithms, our scientists are making discoveries across science and technology, and addressing emerging obstacles like complex mathematical models and challenging datasets.

Making better decisions

While more data is being collected and stored than ever before, it only has value once it's transformed into information and decisions. Understanding the strengths and limitations of statistics, machine learning and artificial intelligence equips our researchers with the necessary tools to make decisions for a better world.

Emerging applications

QUT's research is rooted in the real world. Applied data science is producing solutions to data challenges brought to us by industry. The variety of real-world industry problems our researchers face drives the very innovation that makes us thrive as we develop new solutions, methods and algorithms with impact.

Artist's impression of Queen's Wharf development. Source: Destination Brisbane Consortium. Concept image only, subject to approval.

THE LABS 2020

MATERIALS SCIENCE

Centre for
Materials Science

A scientific engine room for designing and developing new materials with adaptable properties and specific functions.

NARROW THE FOCUS TO SPEED RESEARCH TO OUTCOMES:
Bridging the research-industry divide

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ABOVE Professor Jose Alarco.

Bridging the gap between fundamental research and product development requires a substantial, risk-moderated investment that is not only possible but necessary, according to materials scientist Professor Jose Alarco.

Alarco is an expert in the complex world of batteries—everything from energy-dense materials, storage and life cycle to improved safety through development of ceramic-coated separators and battery pack design.

Batteries are essential to the future of transportation, portable electronics, and the storage and efficient use of renewable energy, but market demand is outstripping the speed of science, which often requires proof of concept and pilot-scale results to prove commercial viability.

However, Alarco says there is a shortcut proven to attract industry investment.

"Fundamental research is essential, but big funding has to come from commercial activities—from profitable companies that can afford to invest back into research," Alarco said.

ABOVE Pilot-scale experiments cost time and money. Alarco uses computational modelling to target relevant experiments and better align the research time frame with industry expectations.

"Researchers will increasingly look to industry for funding, but commercial enterprises will look for ways to make money when deciding on good investments.

"Focusing on fundamental research with an immediate or near-future market application will help researchers attract industry investment.

"If researchers are going to have an impact on funding, we need to demonstrate the viability of our fundamental research with experimentation that gets us as close as possible to a real product for which there is an existing market.

"We also need to have viable, preliminary cost projections that indicate potential returns on investment for the developed product.

"The best way to accelerate the answers is to combine experimental and theoretical work, addressing all the practical product requirements specified by the industry."

Use computational modelling to target relevant experiments

Fundamental research aims to improve scientific theories while applied research uses those theories to develop new products or technologies.

Alarco does both and aims to see industrial outcomes from his fundamental research within 5 years from project commencement, or earlier if possible.

Once the theoretical groundwork has been established and validated, he expedites the research journey by using computational modelling to simulate outcomes, which narrows the field of exploration and targets relevant experiments.

"Computational modelling can save a lot of time and money in terms of experimentation costs. Even the few subsequent experiments you conduct will fit within a validated theoretical framework and almost immediately give your applied research context for interpretation," Alarco said.

"The initial workload is similar to an empirical research approach, but the time frame afterwards is condensed by combining theory with just a few targeted experiments."

After the initial theoretical work has been carried out, using further computational modelling may better align the research time frame with industry expectations.

"A lot of groundwork is done in the first year, but in a week or two after that you can almost answer the problem you want to solve experimentally," Alarco said.

"It's an unusual way of experimentation but it's proven to get industry involved."

While Alarco uses computational modelling as a shortcut to outcomes in his own experimental research, he says there can be an academic trade-off.

"The outcome of experimentation is what brings in funding but can delay academic publication. However, once we achieve funding, we can go back to complete the fundamental work.

"You can also use modelling to target which fundamental aspect of the research you should be publishing."

Modelling industrial applications

Alarco uses computational modelling in his research on new battery technologies through the QUT Centre for Materials Science, QUT Centre for Clean Energy Technologies and Practices, Future Battery Industries Cooperative Research Centre, and the ARENA H2Export program.

To assess larger scale batteries for grid applications, his colleagues also model design and performance using a variety of programs.

"There are software packages used in industry that are amazing tools for multi-scale development of batteries from material stages all the way to performance in engineering applications," Alarco said.

"One can model the material of an electrochemical cell, how it would perform in the cell, with different electrolytes and in a pack design."

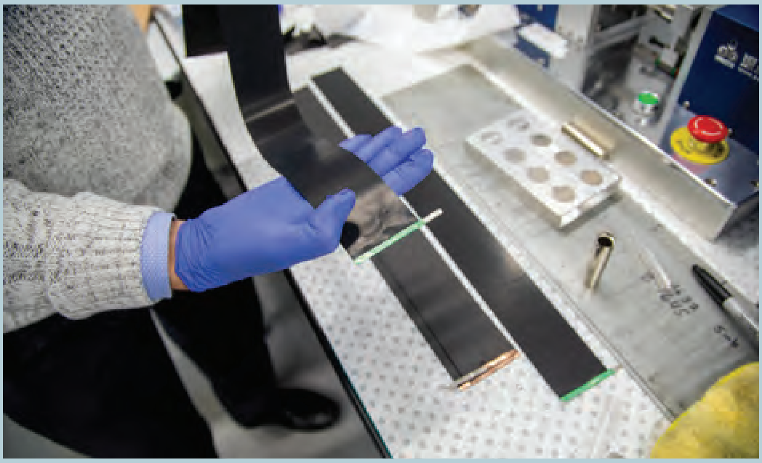
Improved battery safety can also be modelled by optimising maintenance cycles, and monitoring or replacing cells if one deviates from its performance.

"In pack design you need some ability for heat dissipation, otherwise the electrolyte could become unstable. If one cell gets too hot it can catch fire, which is called thermal runaway," Alarco explained.

"This can also lead to thermal propagation—where one cell heats an adjacent cell with more catastrophic results. So, battery pack design is certainly a safety issue, particularly for very large packs."

Scaling-up samples and packaging

The battery cathode and anode typically consist of powder materials, which are mixed with conducting additives, binders and solvents, to be made into inks that are printed onto the respective conducting electrodes.



Battery powders are printed onto conducting electrodes.

A cylindrical roll comprised of the coated cathode, coated anode and porous polymeric separator. The roll is inserted into a battery can and subsequently filled with electrolyte.

ABOVE Pilot-scale demonstrations give confidence to industry that academic research and development is truly scalable. Alarco helped establish the QUT pilot plant for battery powder manufacturing.

Alarco is particularly focused on the design of the multiple interfaces in a battery cell—including those between metal collectors, cathodes, anodes, electrolytes and separators—that improve energy sustainability and efficiency and increase the safety of batteries with high energy density.

Match your research vision with market demand

In addition to increased safety and performance, market demand for batteries with higher energy density is also driving global research.

Alarco uses computational modelling to design new materials and predict performance.

"We haven't even fully developed all the characteristics for some of the promising materials the battery market wants but safe, high energy density is the goal" Alarco said.

The higher the energy density of a material, the greater the amount of energy stored in its mass, but often only part of the energy can be extracted before the integrity is compromised.

Smaller, lighter materials that store more extractable energy than current battery materials are of great interest to companies dealing with portable technologies such as mobile phones.

Alarco is particularly focused on the design of the multiple interfaces in a battery cell—including those between metal collectors, cathodes, anodes, electrolytes and separators—that improve energy sustainability and efficiency and increase the safety of batteries with high energy density.

Computational tools allow Alarco to design materials and interfaces with predicted properties before he validates those predictions with experimental evidence.

Based on successful experimentation, and if a valid commercial demand is justified, Alarco will then translate lab results to pilot scale processes.

Collaborate with industry on targeted experiments

Alarco sources the material for his ceramic-coated separators from the Lava Blue pilot plant.

QUT's Associate Professor Sara Couperthwaite established the pilot plant with Lava Blue and the Innovative Manufacturing Cooperative Research Centre to prove her tailored chemical processing of high purity alumina (HPA) from low-value kaolin clay at industrial scale.

"We synthesise the HPA to meet required specifications, while maintaining a >99.99 per cent purity level," said Couperthwaite, an industrial chemist with the QUT School of Mechanical, Medical and Process Engineering.

"With the HPA, researchers can then work out how to prepare the material as a battery separator coating and eventually test its performance."

Alarco says the ceramic properties of HPA make it appealing as a protection barrier for the polymeric separator material.

"Alumina is ceramic, which generally refers to very refractory material. It is one of those very stable metal oxides that can go to very high temperatures without change," Alarco said.

"A battery could overheat by several hundreds of degrees. If the polymeric separator melts and disappears but the ceramic remains in place, it prevents a shortage between the cathode and anode."

Alarco's team develops, characterises and optimises the alumina particles for coated separators then validates performance in battery cells.

"We ensure the alumina particles are at the optimum size and porosity to allow the right adhesion onto the porous polymeric membranes, then test the properties of these coated separators," Alarco said.

"Nail penetration tests can show if the new battery is safer by contrast and doesn't overheat as much when a cell is punctured.

"Potential battery penetration is the reason flight attendants tell you not to try to retrieve a dropped mobile phone. If you recline your seat to look for it and the phone is caught in the mechanism, it can be punctured and start a fire."

Scaling-up samples and packaging

While aligning fundamental research to target commercial applications will make projects more attractive to investors, pilot-scale plants are also building bridges between academia and industry.

"There are limited groups doing translation work to industry scale and industry decision makers won't usually involve themselves in anything small-scale unless it's of strategic value," Alarco said.

"If you have something of interest you need to be prepared to invest in upscaling samples."

Alarco speaks from experience having helped establish the pilot plant for battery powder manufacturing and Australia's first dry room labs for lithium ion cell manufacturing, both based at QUT.

The battery cathode and anode typically consist of powder materials, which are mixed with conducting additives, binders and solvents, to be made into inks that are printed onto the respective conducting electrodes.

"We started with battery powder. When we had that we worked on the cells and are now getting more involved in battery pack design. Eventually we will progress to working on the battery management system," Alarco said.

Packaging new materials as products also has a big impact on investment success.

"The black powder we use in batteries would look like a dirty mess to an investor. But, if we show them how to make that into a battery that can be used in their radio or house, they understand its value.

"Likewise, scientifically and technically we have very good work in terms of sensors and devices, but a prototype might look like a board with a number of wires going everywhere.

"If you can afford the design work to package your device as a neatly presented commercial product, that prototype is probably going to be the one to attract funding."

REDUCING INDUSTRIAL-SCALE RISKS: Lava Blue's sensor-rich pilot plant

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Lava Blue and QUT will partner on a $1.5m pilot plant in late 2020 to transform manufacturing of high-purity alumina (HPA) and remove the technical risk of scaling-up production to 5000 tonnes per year.

BELOW (LEFT TO RIGHT): QUT's Dr Rachel Pepper and Associate Professor Sara Couperthwaite with Lava Blue partners Michael McCann and Sylvia Tulloch.

High-purity alumina (HPA) (Al_2O_3) is a chemically inert ceramic material with high thermal and electrical resistivity, which makes it a critical component in the production of many high technology applications including electronic displays, semiconductors, sapphire glass, and separators for both lithium ion (Li-ion) and aluminium batteries.

Mining company Lava Blue found large deposits of kaolin clay while mining for cobalt blue sapphire in its North Queensland mineral properties.

In 2018, QUT industrial chemist Associate Professor Sara Couperthwaite and her team successfully produced >99.99 per cent HPA from the low-value clay at lab scale and have continued to improve the quality and manufacturing process since.

Scaling highly controlled production

Now Couperthwaite leads construction of a pilot plant to scale-up production from both science and engineering perspectives, in collaboration with Lava Blue and the Innovative Manufacturing Cooperative Research Centre.

"The process of leaching the clay to produce HPA offers a simple alternative to the current industry model of producing HPA, which involves a chain of production processes across different industries," Couperthwaite said.

"The sensor-rich pilot plant is designed to produce 20 kg batches of HPA and will enable us to remove the technical risk of scaling up to an initial commercial production of 1000 tonnes per annum."

HPA value is determined by product attribute metrics including purity, particle size, particle size distribution, phase of crystallinity and other properties.

Maintaining a high degree of process control allows HPA with tailored attributes to be produced for different end uses, such as Li-ion battery separators, LEDs and sapphire glass.

"Integrating machine learning to in-line real-time monitoring devices and sensors allows us to tune the pilot plant to provide optimal performance as well as minimise waste generation," Couperthwaite said.

"The plant itself is also optimised through parallel programs on wastewater recycling and treatment, and on thermodynamics for energy efficiency."

ABOVE Associate Professor Sara Couperthwaite is partnering with mining company Lava Blue, to lead a project to transform kaolin clay into high-purity alumina.

Being able to produce 20 kg batches of HPA to very precise requirements will allow Lava Blue to qualify its products into the very specific requirements of customer supply lines, while developing an understanding of the critical issues required to scale highly controlled production.

Minimising capital expenditure and eliminating commercial risk

Lava Blue's investment in the pilot plant is expected to significantly minimise capital expenditure and largely eliminate the technical risk of establishing its first commercial plant at Charters Towers, according to managing director Michael McCann.

"The focus of this science and engineering effort is to truly understand what we're making and how best to do that while aiming to design a lowest possible capex to produce a 1000-tonne-per-annum production train," McCann said.

"Once the first production train is commissioned at Charters Towers, we will construct parallel trains with the goal of producing at least 5000 tonnes per annum of high-purity alumina."

As well as delivering the feedstock for HPA mining operations, Lava Blue's mine also produces gemstones and clays for cosmetics as valuable by-products.

Strategically positioned for collaboration

Lava Blue was offered a site for its HPA pilot plant at the Redlands research facility in Brisbane, which provides strategic and practical advantages to collaborate with researchers on clean energy, future agriculture, and zero waste technologies and practices.

"The Redlands research facility provides synergistic opportunities for planned pilot plants in energy, which will strengthen our hub of research," Couperthwaite said.

"It is the proposed home of Australia's only National Battery Testing Centre supported by the Future Batteries Industry Cooperative Research Centre which includes a QUT battery fabrication team that works closely with Lava Blue to trial the 4N HPA developed by our own research team.

"Being able to fabricate battery components and test them to Australian and international standards in the same research facility will position Lava Blue to lead development of the most advanced and customised forms of this material for batteries and for other applications."

Electronics and renewable energy markets are among those driving global demand for HPA, an important material for use in separators required to maintain the stability and safety of Li-ion batteries, which often need increasingly pure and specialised metals and materials.

Couperthwaite is already collaborating with Professor Jose Alarco and Dr Wayde Martens from the QUT Centre for Materials Science to incorporate this HPA into new superconductor technologies.

Lava Blue's primary research facility with processing equipment has a planned 300 m^2 footprint and will include an environmentally controlled clean room and analytical laboratory.

Additional auxiliary research areas include demountable offices and storage for 100 tonnes of material. The total site size for the Lava Blue research facility is 1600 m^2.

CRITICAL BUILDING BLOCKS:
Diamonds to power future technologies

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The new carbon structure could be a potential micro-scale power supply for anything from implanted biomedical sensing systems monitoring heart and brain functions, to small robotics and electronics.

QUT researchers have proposed the design of a new carbon nanostructure made from diamond nanothreads that could one day be used for mechanical energy storage, wearable technologies, biomedical applications and more.

Dr Haifei Zhan and colleagues successfully modelled the mechanical energy storage and release capabilities of a diamond nanothread (DNT) bundle—a collection of ultrathin one-dimensional carbon threads that store energy when twisted or stretched.

“Similar to a compressed coil or children’s wind-up toy, energy can be released as the twisted bundle unravels,” said Zhan, a member of the QUT Centre for Materials Science and School of Mechanical, Medical and Process Engineering.

“If you can make a system to control the power supplied by the nanothread bundle it would be a safer and more stable energy storage solution for many applications.”

The new carbon structure could be a potential micro scale power supply for anything from implanted biomedical sensing systems monitoring heart and brain functions, to small robotics and electronics.

"Unlike chemical storage such as lithium ion (Li-ion) batteries, which use electrochemical reactions to store and release energy, a mechanical energy system itself would carry much lower risk by comparison," Zhan said.

"At high temperatures chemical storage systems can explode or can become non-responsive at low temperatures. These can also leak upon failure, causing chemical pollution.

"Mechanical energy storage systems don't have these risks, which makes them more suited to potential applications within the human body.

"Carbon nanothread bundles could be made into twist-spun yarn-based artificial muscles that respond to electrical, chemical or photonic excitations.

"Previous research has shown such a structure made with carbon nanotubes could lift 50 000 times its own weight."

Zhan's team found the nanothread bundle may be more robust and better performing than nanotube systems.

"Nanothreads outperformed nanotubes, which collapsed when overtwisted, making the structures unstable and unpredictable.

"Nanothread bundles do not have the instability issue of carbon nanotube bundles because nanothreads have an ultrathin diameter whereas nanotubes are like thin-walled tubes."

Critical building blocks in future technology

Zhan's new nanostructure will be a critical building block in the family of systems used in many modern electronics like mobiles and computers.

Nanoelectromechanical systems (NEMS) and microelectromechanical systems (MEMS) combine a nano or microsized mechanical power supply—such as Zhan's nanostructure—with an electrical component that receives signal commands.

"Any devices with a touch screen like our mobile devices, for example, may have many microelectromechanical systems ," Zhan said.

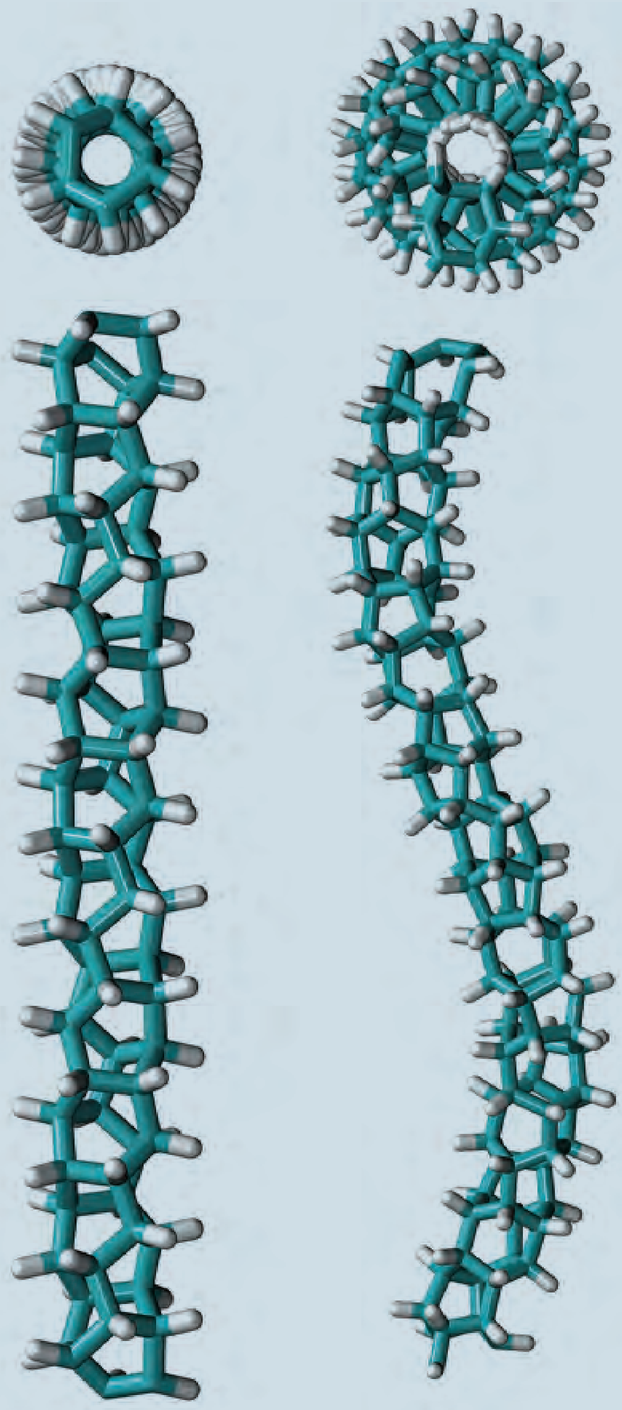
"When we touch the screen, the mechanical force transfers to an electrical system, which then transfers that signal to the main board."

Miniaturisation or minimisation of these electro-mechanical systems is also the reason these devices are getting smaller and more energy efficient.

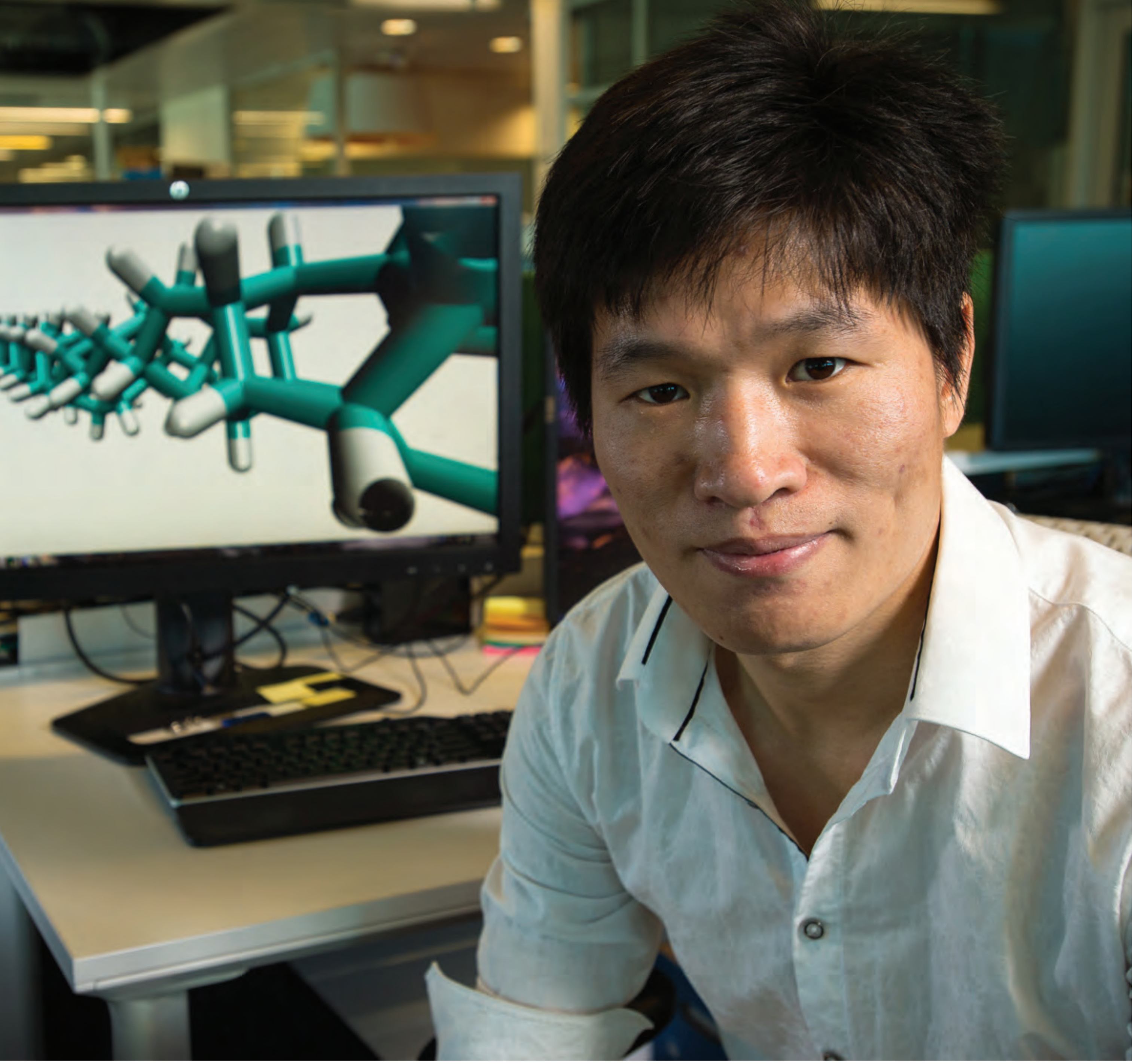
"The first computer occupied 1800 square feet and weighed almost 50 tons. Now we have laptops. Nobody carries a big heavy mobile anymore. These are now smaller and thinner," Zhan said.

Nanothread bundles may be more robust and better performing than nanotube systems for mechanical energy storage. Unlike nanotubes, nanothreads have an ultrathin diameter which makes them less likely to collapse when twisted or overstretched.

Fifty different types of nanothreads have been theoretically predicted, with 15 of those possessing the most stable structures.



ABOVE Achiral (LEFT) and chiral nanothread (RIGHT) types with cross-section views (TOP).



ABOVE Dr Haifei Zhan proposed the design of a new carbon nanostructure made from diamond nanothreads which could be used as a mechanical energy storage system.

"Smaller devices have a train of benefits including the need for less energy, greater energy efficiency and reduced material costs.

"A battery that powered a larger device for 5 hours might charge a smaller device for 10 hours. I think everything in the end will come down to energy and weight."

Energy density matters

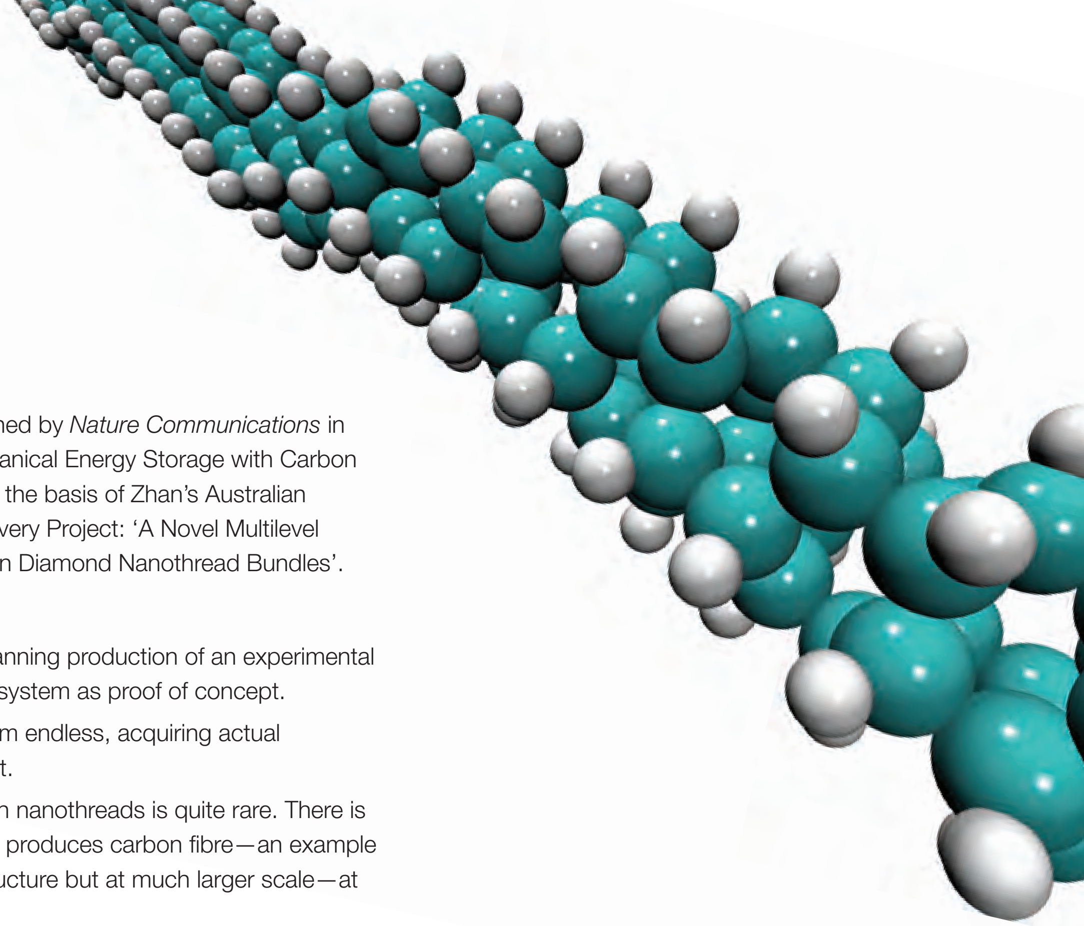
Zhan's team found the nanothread bundle's energy density—how much energy it could store for its mass—was 1.76 MJ per kilogram, which was 4–5 orders higher than a conventional steel spring, and up to 3 times compared to Li-ion batteries.

"Energy-dense materials are very important for many applications, which is why we are always looking for lightweight materials that still perform well," Zhan said.

"The benefits for aerospace applications are obvious. If we can reduce the weight of a system, we can significantly reduce its fuel requirements and costs."

The application of carbon nanothread bundles as an energy source could be endless, according to Zhan.

"The nanothread bundles could be used in next-generation power transmission lines, aerospace electronics, batteries, intelligent textiles and structural composites such as building materials."



Research findings were published by *Nature Communications* in the paper: 'High Density Mechanical Energy Storage with Carbon Nanothread Bundle', and form the basis of Zhan's Australian Research Council (ARC) Discovery Project: 'A Novel Multilevel Modelling Framework to Design Diamond Nanothread Bundles'.

Rarer than diamonds

Zhan and his team are now planning production of an experimental nanoscale mechanical energy system as proof of concept.

But, while the applications seem endless, acquiring actual nanothreads may prove difficult.

"Industrial production of carbon nanothreads is quite rare. There is only one place in Australia that produces carbon fibre—an example of one-dimensional carbon structure but at much larger scale—at industrial scale," Zhan said.

The road to application is also historically long.

"The applications of carbon nanotubes are discussed widely today in anything from electronics and sensors to textiles, civil engineering, aerospace and medical devices, but these were first synthesised almost 30 years ago in 1991," Zhan said.

"Likewise, theoretical predictions of carbon nanothreads can be dated back to nearly 20 years ago but weren't synthesised until 2015."

For Zhan, though, the benefits of working with nanothreads means this complicated journey is worth the work.

"Carbon is such an abundant, cheap, light and stable material—more stable than metal.

"The cost of producing materials at the nanoscale is still quite high, but as it becomes cheaper we will hopefully see more novel materials and applications."

Zhan said the research team will spend the next 2–3 years building the control mechanism for the system to store energy—the system that controls the twisting and stretching of the nanothread bundle.

This research was funded through the ARC Discovery Projects scheme and was a collaboration between the QUT Centre for Materials Science; Agency for Science, Technology and Research in Singapore; and the National University of Singapore.

"The nanothread bundles could be used in next-generation power transmission lines, aerospace electronics, batteries, intelligent textiles and structural composites such as building materials."

DR HAIFEI ZHAN

PLASMONIC 'LIGHT TWEEZERS': Using solar energy to move molecules

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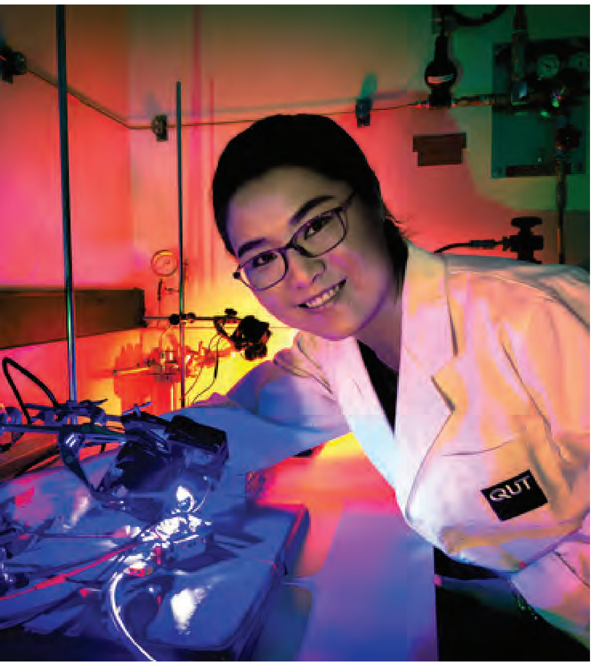


ABOVE Dr Sarina Sarina

In a scientific breakthrough, Dr Sarina Sarina has used sunlight to power a targeted and reversible process for chemical reactions that could be used to capture and convert molecules from raw materials into ingredients for medicines, intermediates and other valuable products.

Molecules are 10 000 times smaller than a cell—too small for a mechanical tweezer to move.

Sarina's group from the QUT Centre for Materials Science has optimised a process called "plasmonic optical trapping".

Dubbed "light tweezers", the process uses visible light and nanoparticles to create a plasmonic optical force capable of moving molecules through a solution.

"Until now, it was believed that intense optical force could only be generated by lasers," Sarina said.

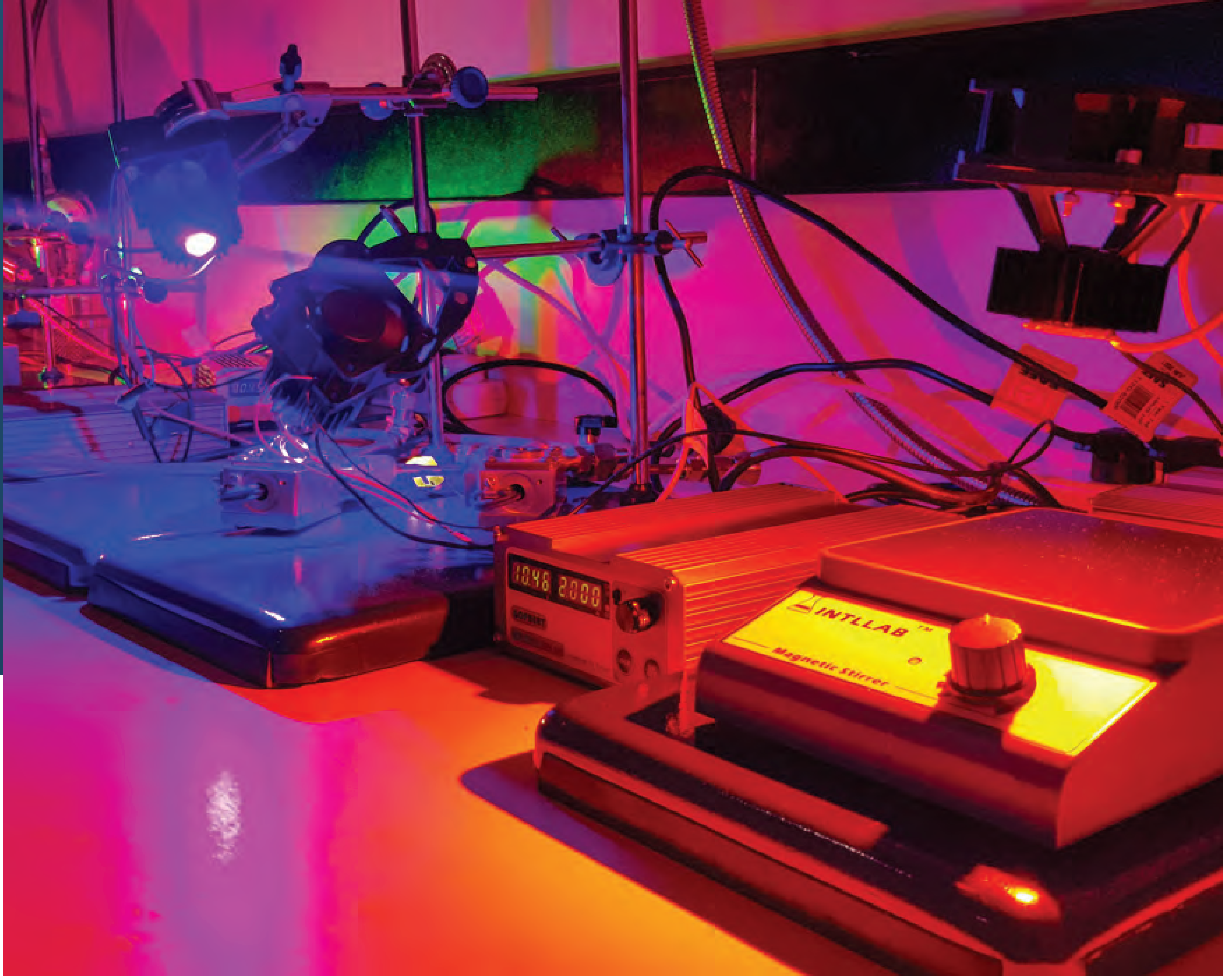
"We discovered how to use low-intensity visible light to generate enough plasmonic optical force to move molecules by introducing metallic nanoparticles to the solution."

Plasmonic optical force is created when gold, silver and copper nanoparticles absorb light and dissipate excess energy as an electromagnetic field strong enough to attract or repel molecules based on polarity—the positive and negative charge.

"We can target molecules of interest by their polarity strength and draw them to the catalyst surface, then convert them into important products of interest or remove them from the solution," Sarina said.

"This process lets us control a chemical reaction better and avoid by-products.

"It is a greener process because photocatalysts accelerate a chemical reaction with light, not with fossil fuels.



ABOVE Lamps are used in lab experiments to irradiate nanoparticles with visible light. Different light intensities determine the strength of the nanoparticle's electromagnetic field.

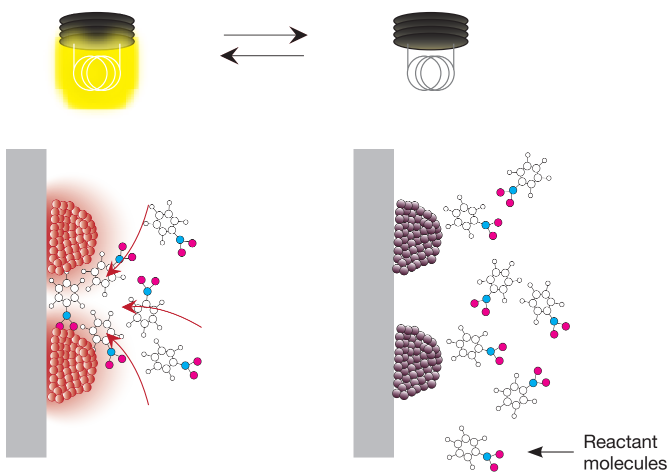
"Light-induced reactions are also about 1000 times faster than thermal processes in a solution with a very low concentration of molecules, which means we see results in less time using less energy."

Using the visible light spectrum, which accounts for 47 per cent of solar energy, is also what allows Sarina to tune the electromagnetic field to target specific molecules.

"Each molecule has a different polarity. Changing the lumens—the intensity of light—into the nanoparticle will change the strength of its plasmonic optical force, attracting different molecules by polar strength," Sarina said.

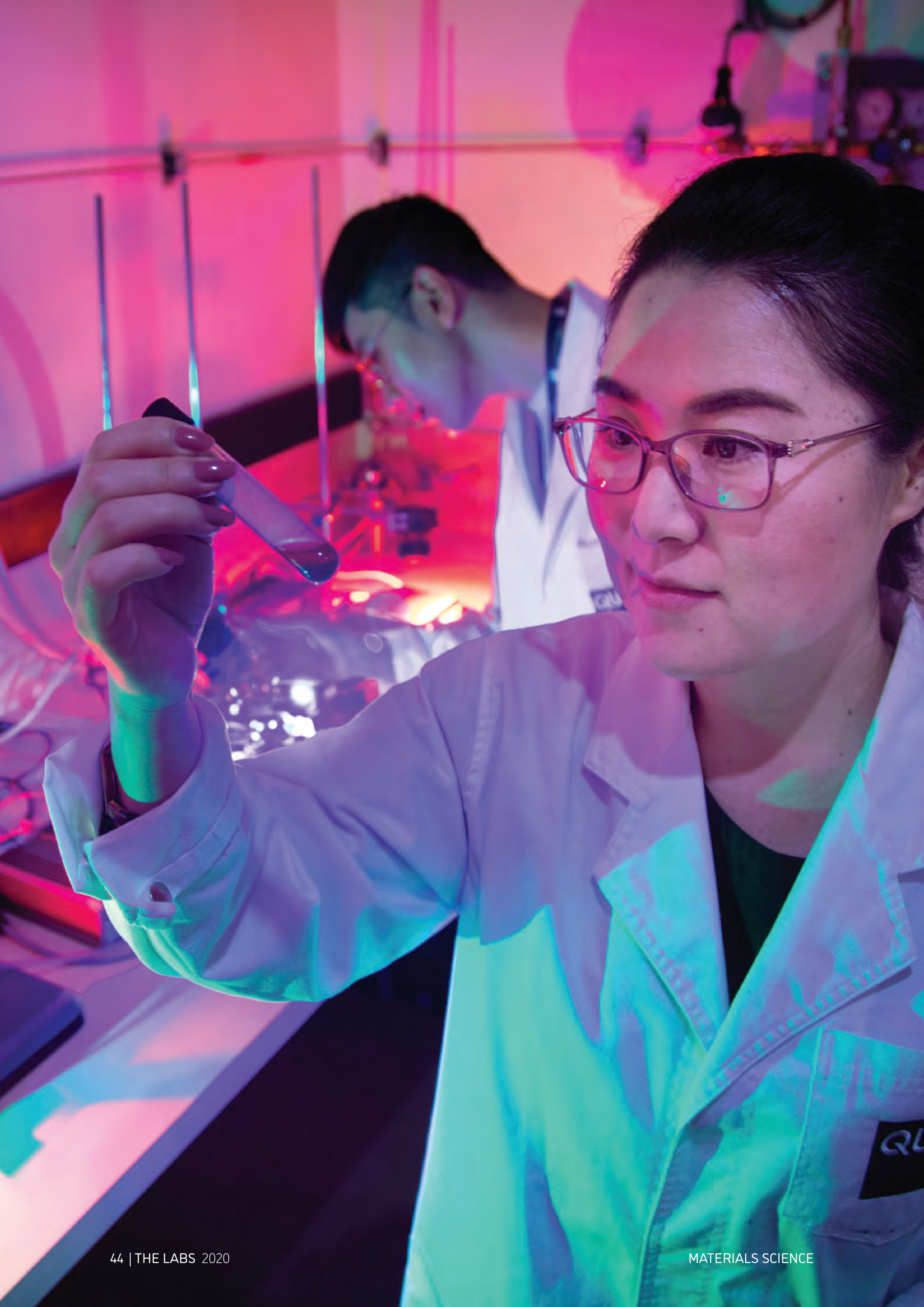
"However, not all metal nanoparticles can work this way with light. Only gold, silver and copper have plasmonic properties."

BELOW Irradiated plasmonic nanoparticles attract molecules when the light is on and release them when the light is off.



Plasmonic metal nanoparticles under irradiation, red area is electromagnetic field and molecules are being trapped.

Plasmonic metal nanoparticles without irradiation.



A chemical reaction with an on-off switch

Unlike thermal processes that affect all molecules in a solution, light-induced trapping is not only selective but reversible.

"Molecules are trapped when exposed to light, but released when the light is turned off, or vice versa depending on the polarity."

This light-switching process has wide potential applications in chemical synthesis design and product control, according to Sarina.

"The control of product selectivity in organic reactions has always been, and still remains, an ongoing challenge.

"But plasmonic optical trapping can address the challenge in a smart way. We can trap a molecule and control its reaction ratio to achieve various products from the same solution."

In a solution containing alkyne and amine molecules, for example, Sarina can switch reaction pathways by turning the light on or off to create both imines and diynes.

"Light-on will create imines from the reaction of alkyne and amine, while light-off will achieve diynes from the reaction between alkyne and other alkyne molecules," Sarina said.

"Imines are intermediate molecules used to synthesise alkaloids, which are used to make quinine for antimalarial drugs, ephedrine for anti-asthma treatment, and homoharringtonine for anticancer drugs.

"Diynes are used to produce polymer materials that are widely applied to sensors."

The process could also be applied to create more accurate and sensitive sensor or gas detector technology, according to Sarina.

The next steps

While Sarina and her team have proven the optimised plasmonic optical trapping process in bench-scale studies of solutions less than 100 ml, scaling up the process will be the focus of future research.

Findings were published in the *Angewandte Chemie International Edition* as "Plasmonic Switching of Reaction Pathway: Visible-Light Irradiation Varies Reactant Concentration at the Solid-Solution Interface of a Gold-Cobalt Catalyst", and in *Chem* as "Promoting Ni (II) catalysis with plasmonic antennas".

Her research builds on her previous work using light instead of fossil fuels to drive chemical reactions at room temperature, a focus which won her the prestigious Alexander von Humboldt fellowship in Germany.

Sarina's current project is part of her Australian Research Council (ARC) Discovery Early Career Researcher Award (DECRA) grant to use plasmonic metal photocatalysts for selective organic reaction. She continues to collaborate with senior QUT researchers Professor Huai Yong Zhu, Associate Professor Eric Waclawik, and Professor Godwin A. Ayoko.

"We can target molecules of interest by their polarity strength and draw them to the catalyst surface, then convert them into important products of interest or remove them from the solution."

DR SARINA SARINA

NEW POLYMERISATION TECHNIQUE: Truly biodegradable plastic that could end ocean waste

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ABOVE Dr Hendrik Frisch

> "Our research goal is to produce fully biodegradable plastics so even microplastics are recognised by microorganisms as food."
>
> DR HENDRIK FRISCH

Imagine a shopping bag with the strength of Kevlar® but the biodegradability of whatever's sitting at the bottom of your crisper.

With the right chemistry, our old love affair with plastics could be reignited by new research into intelligent polymers that break down on command.

Dr Hendrik Frisch from QUT's Soft Matter Materials Laboratory, affiliated with QUT's Centre for Materials Science and School of Chemistry and Physics is developing an innovative technique to make tailored, remotely controllable plastics and other polymers.

"Many current biodegradable shopping bags still have a very limited biodegradability under real world conditions, especially in marine environments," Frisch said.

"Our research goal is to produce fully biodegradable plastics so even microplastics are recognised by microorganisms as food."

Frisch's research will combine the radical polymerisation method used to make plastics with the natural building blocks of peptides to create a new class of high-end hybrid polymers.

The new polymerisation technique would be compatible with today's polymer production methods and thus contribute to a move towards more sustainable plastic materials, according to Frisch.

"Polymer chains in plastics—whether that's a plastic bag or takeaway cup—are made up of really long linear chains we call the polymer backbone.

"For most polymers, a carbon backbone brings them together. We know how to attach natural building blocks to the sides of these carbon backbones but the backbone itself doesn't break down.

"That is the reason a polystyrene cup thrown into the ocean will stay there for a very long time.

"It has a molecular structure that doesn't exist in nature, which is why there are no enzymes or natural biological building blocks that can break it down."

Hybrid molecules recognised by nature

Frisch and his team aim to incorporate selected natural peptides into the carbon backbone of polymer molecules to control the properties of the resulting polymer-peptide hybrid materials.

"The molecule would assemble or disassemble in response to its chemical or biological environment," Frisch said.

"This will allow us, for instance, to translate the degradability of natural building blocks into plastic materials.

> "If plastic becomes readily degradable, we will take great steps towards fighting plastic pollution, particularly in marine environments, which is one of the greatest threats to the future of our planet."

Other customisable functions

Seemingly contradictive to degradability, the ability to insert the natural building blocks into synthetic polymer also holds potential for the design of robust materials.

"By embedding peptides that strongly interact or stick to each other, like spider silk, we can control the interactions between different polymer chains," Frisch said.

"Specific peptides within spider silk make it a highly organised and robust structure, offering strength and extensibility beyond most man-made fibres.

"If combined with the right peptide sequence and synthetic polymer, we could mimic that performance.

"Such interactions between polymer chains are key to the function of high-performance polymers used for armour and aerospace research, such as Kevlar® and Technora®."

The possibility to tailor polymeric materials towards endurance, triggered mechanical transformation and degradability is extremely promising for industrial and medical applications, according to Frisch.

"We could design materials where we use external stimuli, like pH levels, to turn toughness, endurance, degradability or other features on or off.

"I hope to tailor hybrid materials so that we can make things with a biological use—like implants that have natural sequences recognised by the body.

"The body's responses to foreign material, like inflammation and other immune responses, can lead to implant rejection.

"If we can introduce specific natural peptide sequences into the coating of implants, the body could recognise the hybrid materials and prevent unwanted responses."

Materials with natural sequences recognised by nature would also provide an opportunity to establish completely new manufacturing processes.

"There are some manufacturers of high-performance polymers in Australia, but the production of intelligent polymers would be a completely new stream of manufacturing," Frisch said.

Frisch received an Australian Research Council (ARC) Discovery Early Career Researcher Award (DECRA) Fellowship in 2020 for his research project: "Programming Polymer Function via Ring-opening Polymerisation of Peptides".

Bringing this new class of polymers into action, Frisch will spend the next 3 years exploring how the embedded peptide sequences can be programmed, but expects to have proof of principle results within 1-1.5 years.

Strong backing

Frisch and his team are embedded in QUT's Soft Matter Materials Laboratory and are mentored and sponsored by ARC Laureate Fellow Professor Christopher Barner-Kowollik and his group.

Initiating strong new independent research streams while being embedded in a world-leading research group is a powerful blueprint for the development of highly innovative and successful early career researchers—a process that QUT seeks to adapt across its research endeavours.

Frisch will collaborate with other experts from QUT's chemistry and physics research community, including those within the Central Analytical Research Facility (CARF).

To analyse the microstructures of the materials, he will also draw on expertise from QUT's Inorganic Nanomaterials Laboratory led by QUT's ARC Laureate Fellow Professor Dmitri Golberg.

"There are some manufacturers of high-performance polymers in Australia, but the production of intelligent polymers would be a completely new stream of manufacturing."

DR HENDRIK FRISCH

A POWERFUL NEW SEMICONDUCTOR: Diamonds could be the ‘crown jewel’ in future electronics

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Diamonds could be everyone’s best friend with new research unlocking hidden properties for next generation electronics.

Associate Professor Dongchen Qi from the QUT Centre for Materials Science led research that transformed the intrinsically inert diamond into a powerful semiconductor capable of sustaining very high power and withstanding conditions too extreme for silicon devices.

The discovery could herald future electronics with powerful new properties that will enable next-generation military, aerospace and telecommunications applications.

“Diamond, beyond its allure as jewellery, can withstand high-voltage, high-power operations and harsh conditions such as extreme coldness in deep space or high temperatures in electricity grids, for example, but it has no intrinsic conductivity,” Qi said.

“Conductivity is the basis of any electronic device and without it diamonds are just very basic insulating materials.

“We’ve developed technology that modifies the diamond surface to make it conductive and easily controllable, which means we can now start building electronic circuits on its surface.”

Diamond semiconductors would enable very high-power and high-frequency signal amplification and energy conversion unattainable by other semiconductor materials, making them ideal for applications such as satellite communication and broadcasting stations.

“We’ve developed technology that modifies the diamond surface to make it conductive and easily controllable, which means we can now start building electronic circuits on its surface.”

ASSOCIATE PROFESSOR DONGCHEN QI

"Believe it or not, current radio and TV stations still use hundred-year-old technology called vacuum tubes: bulky glass tubes used to control and amplify signals," Qi said.

"Silicon chips aren't used in these applications simply because they cannot sustain high-power operations, but diamond could."

Almost all computer chips are built on silicon, a first-generation semiconductor, according to Qi, but diamond is among third-generation semiconductors capable of sustaining higher-power operations.

"People working on telecommunications or power conversion are looking at using gallium nitride or silicon carbide semiconductors, but diamonds could be a cheaper and more energy-efficient option," Qi said.

The QUT research also forms part of an Australian National Fabrication Facility (ANFF) Space Technology Prospectus supplied to NASA for discussions on fundamental research to address operating challenges for electronics in space.

"In deep space applications temperatures can range from a few hundred degrees to minus 100 degrees Celsius," Qi said.

"Normal silicon devices would fail but diamonds are very resistant to this kind of harsh temperature change, and also to cosmic rays and solar radiation."

Doping diamonds

Qi's research team innovated a technique called surface transfer doping by introducing a metal oxide layer just a few atoms thick to withdraw electrons from the diamond surface to enable conductivity.

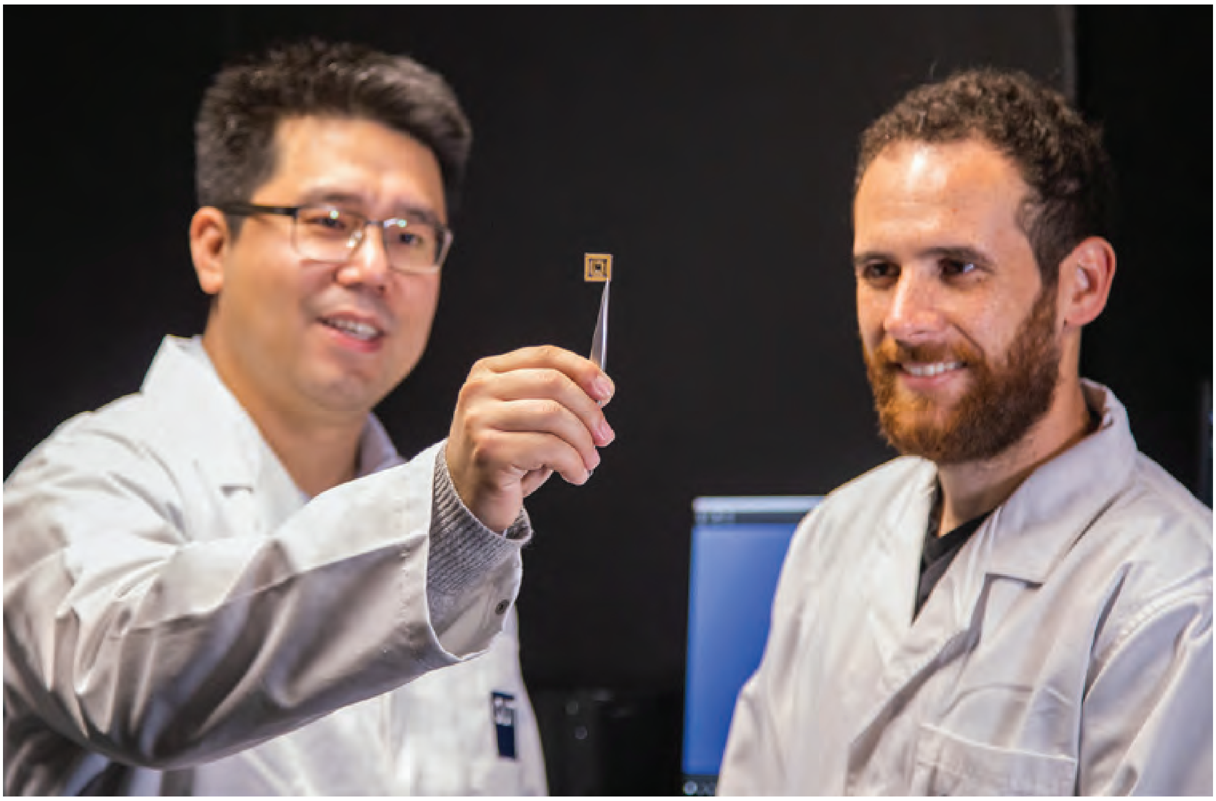
"Diamond is like a city with a fantastic highway infrastructure but no vehicles. In the materials world we call the vehicles charge carriers," Qi said.

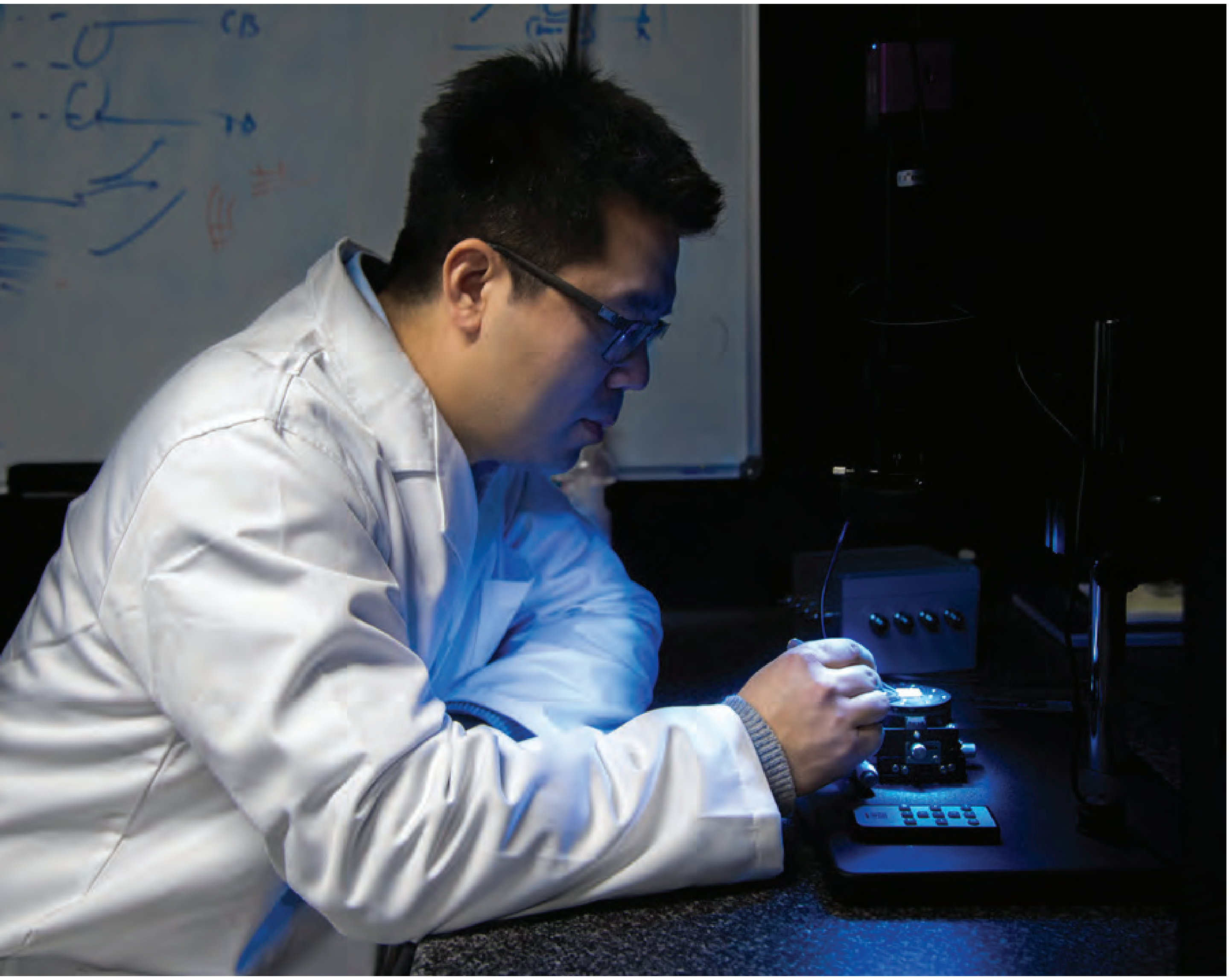
"Our research put vehicles on the diamond roads by introducing charge carriers through the surface acceptors.

"The metal oxide surface acceptors allow us to extract electrons from the diamond surface, leaving holes—a type of charge carrier with positive charge—to make it conductive.

"We can control the surface conductivity of diamond by increasing or decreasing the number of carriers on the road, which we can do by changing the type and coverage of the metal oxide layer."

BELOW Associate Professor Dongchen Qi shows student David Sommers a doped diamond wafer. Metal oxide surface acceptors extract electrons from the diamond surface, leaving holes—a type of positive charge carrier—that make it conductive.





ABOVE Researchers can now start building electronic circuits on the doped diamond surface. Engineering the diamond surface to accept charges also produced an unexpected quantum mechanical phenomenon called spin-orbit coupling, which is at the heart of spintronics technology.

Researchers had to select suitable surface acceptors with an energy level matching that of diamond.

“We started with organic materials, but certain metal oxides worked best with the desired stability in practical devices,” Qi said.

Qi is also a Senior Lecturer and Australian Research Council (ARC) Future Fellow within the QUT School of Chemistry and Physics. Findings, recently published in *Applied Surface Science*, were part of his “Enabling Diamond Nanoelectronics with Metal Oxide Induced Surface Doping” project funded through the ARC Future Fellowships scheme.

Spintronics spin-off from 2D surface phenomenon

Engineering the diamond surface to accept charges also produced an unexpected quantum mechanical phenomenon that could have implications for information technologies.

Qi’s research found that holes confined to the diamond surface formed a two-dimensional (2D) layer that produced a relativistic effect called spin-orbit coupling.

Like the spinning Earth orbiting the Sun, spinning electrons can orbit atoms but generate different energy levels through this interaction.

“Spin-orbit coupling usually happens in heavy-element materials but carbon, which makes up diamond, is such a light element that the effect should have been small.

“The confinement of hole charges to the diamond surface actually induced this phenomenon and gave rise to a very strong effect.”

Observing spin-orbit coupling required an extremely low temperature of only a few Kelvins—minus 270 degrees Celsius—which placed stringent requirements on the device architectures, according to Qi.

“We found diamond devices with palladium electrodes could operate in this extremely low-temperature environment and allow us to observe this intriguing phenomenon.”

Controlling the spin of charge carriers is at the heart of a new spintronics technology that would enable faster and more energy-efficient electronic devices.

“A stronger spin-orbit coupling in diamond means we can control the spins of holes more easily with an electric field,” Qi said.

“That would allow us to fabricate energy-efficient spintronic devices using diamond. That’s perhaps much further away from real applications but is fascinating from a fundamental physics point of view.”

The research was a collaboration between QUT and La Trobe University. Findings were published in *Carbon* as “Strong spin-orbit interaction induced by transition metal oxides at the surface of hydrogen-terminated diamond” and appear in the August 2020 edition of the journal.

Growing industrial-scale diamonds

While diamonds have a combination of properties that make them ideal for electronic devices, Qi hopes the success in achieving a diamond device platform will accelerate complementary research in growing diamond wafers large enough for industrial applications.

“We need large diamond substrates if we are to fabricate millions or billions of devices at the same time for cost efficiency, but the most common synthesised diamond wafer is only a few millimetres across,” Qi said.

“Nowadays, people can grow very high-quality diamond with a process called chemical vapour deposition, feeding hydrocarbon gases like methane with plasmas to grow diamond.

“It is a very slow process and only produces smaller crystals, so researchers around the world have been working on growing larger diamond wafers but the technology is not quite there yet.”

> “Diamond semiconductors would enable very high-power and high-frequency signal amplification and energy conversion unattainable by other semiconductor materials, making them ideal for applications such as satellite communication and broadcasting stations.”
>
> ASSOCIATE PROFESSOR DONGCHEN QI

STUDENT DISCOVERS DIAMOND PHENOMENON: Powering new optoelectronics with light energy

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ABOVE Physics student David Sommers

The generation of photocurrent with visible light adds a whole new dimension to diamond electronics.

QUT physics student David Sommers discovered diamond can generate strong electrical current when exposed to visible light, a finding that could lead to a new species of optoelectronics.

Sommers made the discovery while working with Associate Professor Dongchen Qi from the QUT School of Chemistry and Physics, who recently proved diamonds could become conductive by modifying the surface with metal oxide.

As part of an undergraduate physics capstone research project, Qi gave Sommers a diamond chip with an electronic circuit already formed on the surface so he could investigate if diamond had photocurrent properties.

"I was trying to determine if the electronic circuit could be powered by photocurrent—the transfer of energy from light to an electron within the diamond structure," Sommers said.

"Diamond is insulating, not conducting, so you can't actually get any charge carriers like electrons to move through it in great numbers.

"Modifying the diamond surface with a thin metal oxide layer creates an energy offset to extract electrons from carbon bonds, which basically glue the diamond atomic structure together, and trap them in the oxide layer.

"Electrons that remain in the carbon bonds can then wander around by skipping in and out of 'holes' left behind by electrons that transferred to the oxide."

In semiconductors, holes refer to the absence of electrons but are essentially the same in conducting electricity.

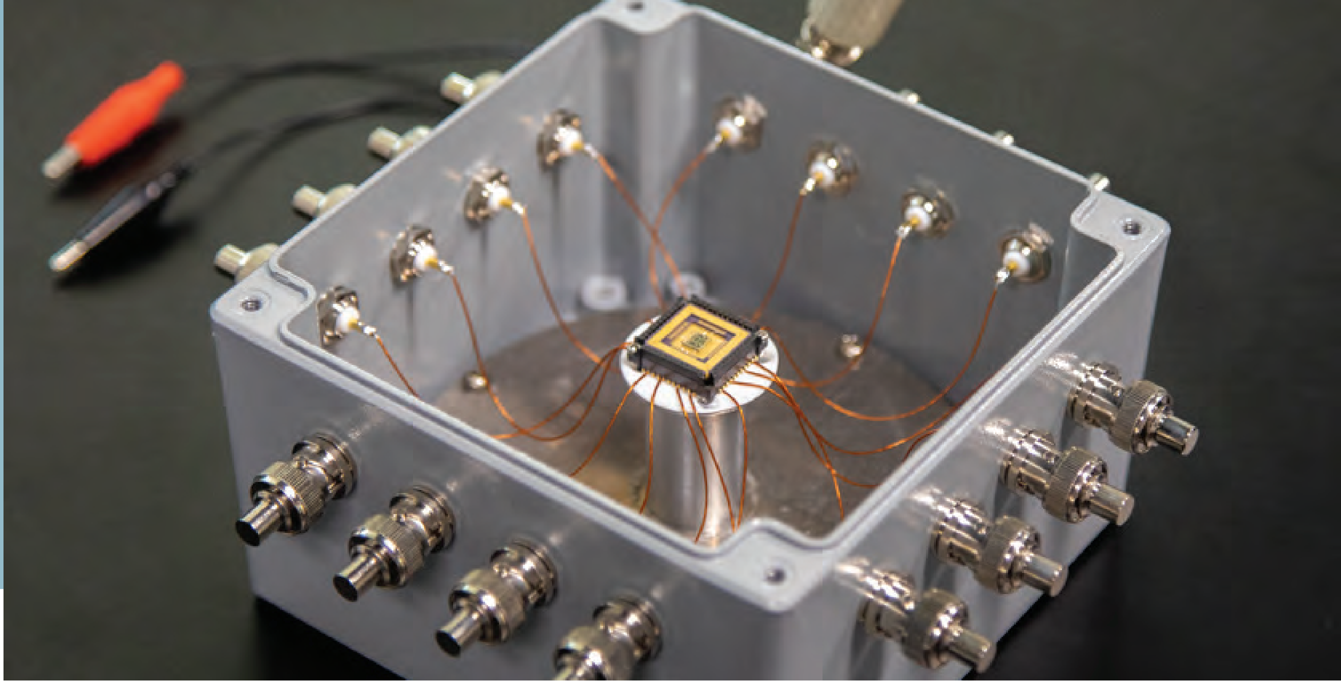
"This process is very akin to a bubble moving through water," Sommers explained.

"A bubble in water is simply a void. Inside the bubble is nothing but the absence of water, but when it appears to move through water what we are actually seeing is the movement of molecules around the void."

More current for less photo energy

Sommers thinks the modified surface layer is the reason his diamond needed less photoenergy to free electrons.

"We think the oxide layer introduced energy states to the diamond bandgap, offsetting the amount of light energy needed to free electrons," Sommers said.



ABOVE Sommers mounts the doped diamond wafer with an electronic circuit on the surface into a device that measures electrical current.

Semiconductors including diamond comprise a valence band with lots of electrons and a conduction band with no electrons.

The energy difference between them is called the bandgap and represents the amount of energy needed to free an electron to the conduction band and create holes in the valence band.

"Our proposed mechanism is that we didn't actually need to excite electrons to the conduction band. We could get hole current in the valence band using less photoenergy by jumping electrons to the surface instead," Sommers said.

The diamond bandgap is large compared to other materials—about 5.5 electron volts (eV), which corresponds to a wavelength of 225 nm for electromagnetic radiation, also known as 'light'.

Shorter wavelengths with less distance between each wave have more energy than longer, loose waves – so the waves with smaller measurements have more energy.

Sommers and Qi expected only ultraviolet light, a short electromagnetic wavelength below 225 nm, would have enough energy to excite the electrons to diamond's conduction band.

"An incoming photon would need an energy equal to or greater than the energy gap to free an electron, but I achieved photocurrent with a green laser about 532 nm, less than half the energy needed," Sommers said.

"I also tested white light, which comprises all visible wavelengths—red, orange, yellow, green, blue, indigo, violet—and measures between 400 nm and 1000 nm.

"Its power was lower than the laser, but it had a larger beam diameter, so more electrons could be photoexcited.

"That created more hole carriers in the valence band and, therefore, more current."

Optoelectronics future

Sommers recently completed QUT's nanotechnology minor, which focuses on skills and knowledge needed to synthesise and characterise nanomaterials. His study helped him understand the principles governing his nanoscale discovery.

Supervisor Qi, who is also a chief investigator with the QUT Centre for Materials Science, said Sommers's findings could be useful in the creation of switches and transistors in new electronic devices.

"In electronics you need transistors, which form the binary logic of electronic devices and allow them to do certain computations. If a transistor as a switch lets current through, for example, it could represent a one or zero: on or off," Qi said.

"Researchers are always looking for new semiconductor and optoelectronic materials, which is what this diamond platform could offer."

The large bandgap of diamond also means it can sustain very high voltages without breaking down, according to Qi.

"Having such a large bandgap makes diamond potentially suited for electronics in high power operations like electricity grids, and technologies in extreme conditions like satellites and deep space applications," Qi said.

INSPIRING FUTURE RESEARCHERS: A really small electronics world with big possibilities

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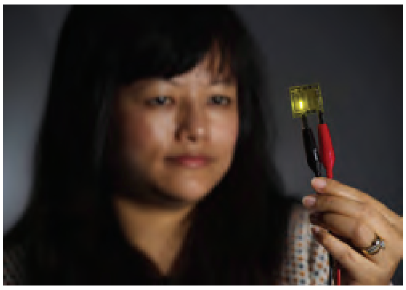

ABOVE Dr Soniya Yambem

As universities shift courses online, physicist and education designer Dr Soniya Yambem is proof of how far curiosity and passion can take a student despite the obstacles.

Yambem is a researcher at QUT where she investigates optoelectronic and bioelectronic devices.

She is also responsible for inspiring up-and-coming researchers and has recruited promising students into the field of bioelectronics, bridging the communication gap between electronic and biological devices that could one day herald prosthetics that actually feel.

Yet, despite the futuristic nature of her work, Yambem's own passion actually grew from very low-tech beginnings.

Growing up in Manipur

Yambem grew up in remote Manipur near the border of India and Burma and read about physics from textbooks.

"Growing up in a developing country, information was quite limited. We had no internet and no computers," Yambem said.

"Maybe I thought what I do now existed somewhere in the world, but I had no idea about it.

"I learned about scientists because my sister had a subscription to the *Junior Science Refresher* magazine.

"I used to read the stories about Nobel Prize winners and tell my dad I wanted to be a scientist. On rare occasions I would listen to radio interviews with doctors and other scientists."

Yambem moved to Delhi after Year 10 to complete her senior years at boarding school.

She studied undergraduate and postgraduate physics at the University of Delhi before undertaking her PhD research in thin film flexible solar cells at the University of Houston in Texas, USA.

In 2011 Yambem moved to Australia for a research position at the University of Queensland before joining QUT in 2015 as a Vice-Chancellor's Research Fellow. Five years on, she is now a senior lecturer.

While her research journey looks straightforward in hindsight, Yambem said it wasn't until she started her postgraduate study that she actually discovered research was a career option.

For this reason, she makes sure her own students know about research and get first-hand experience much earlier in their journey.

Nanotechnology is a modern must-have

Yambem's research focuses on organic electronic devices.

She investigates nanoscale thin films and how to integrate them into electronic components, and then seeks to discover how those work.

She and other researchers use their work to train and inspire students into industry or academic research fields.

Specifically, Yambem runs the Advanced Nanotechnology unit, offers research capstone projects to final-year students and supervises undergraduate students accepted into QUT's Vacation Research Experience Scheme.

> "Nanotechnology is in every sphere of research these days. Nanomaterials have unique properties and can be used in various fields like medicine, pharmaceuticals, materials science, surface science and more," Yambem said.

"Researchers use nanotechnology for everything from exploring nanoparticles for cancer treatment and graphene for supercapacitors, to organic and diamond device development, growing nanomaterials, and studying the application of atomically thin films in surface science."

Students are exposed to research through coursework exercises with known outcomes, as well as problems with undefined outcomes through real research experimentation.

"In theory everything works. But when you actually put that into practice it never turns out the way you expect. In research, if one method doesn't work, you have to find another approach backed by good scientific reasoning," Yambem said.

Students undertaking research units must design and complete experimentation and submit a journal-style paper outlining their aims, method, experimental observations and interpretation of data – everything they would do if employed in an industry or academic research position.

"If I ask students how much light goes through a thin film of gold or silver, based on their research they will need to develop a mathematical model or another technique for analysing that," Yambem said.

"If their understanding is not correct, they will need to keep changing the method until they find one more suitable.

"They are assessed on their application of available methods and whether the theoretical calculation matched the experimental results.

"Their final report needs to make scientific sense and be supported by previous research articles."

ABOVE Dr Soniya Yambem investigates nanoscale thin films and how to integrate them into electronic components, and then seeks to discover how those work. She and other researchers use their work to train and inspire students into industry or academic research fields.

Real research training and learning how to pivot

Every year Yambem and her research colleagues advertise project work for physics students completing their compulsory capstone research.

This has yielded positive results for Yambem, who has discovered a protégé through the program.

Joshua Arthur began his research career after completing Yambem's capstone and vacation research projects and now, under her supervision, is living the lessons learned in the classroom.

In 2019 Arthur received the Endeavour Research Leadership Award to progress his work on understanding organic thin-film transistor technology capable of receiving biological signals.

Electronic interface devices that can seamlessly integrate with the human body have the potential to transform prosthetics into bioelectronic devices that mimic the functions of a real limb.

Arthur attended Queen's University in Canada, which houses excellent optical microscopy equipment capable of looking at the device operations in real time.

Design rules for electronic sensors

As part of his research process, Arthur confirmed valuable knowledge about organic transistors and published design rules for changing the fundamental physics properties of devices that use them.

Hygroscopic insulator field-effect transistors (HIFETs) are a class of low-voltage-operation organic transistors that have been used for biosensing applications—such as monitoring glucose or detecting solvents—through modification of the gate electrode.

"The transistors have three electrodes: the source, the drain and the gate. The gate electrode is used to control the current that flows between the source and drain electrodes," Arthur explained.

"Basically, we showed that improving the conductivity of the gate electrode resulted in better control of the current between the source and drain, which means a much better transistor overall.

Hygroscopic insulator field-effect transistors (HIFETs) are a class of low-voltage-operation organic transistors that have been used for biosensing applications—such as monitoring glucose or detecting solvents—through modification of the gate electrode.

"This is an important step toward designing sensors based on HIFETs."

Arthur and his collaborators are now focused on understanding the electrode better in order to develop new advanced sensors.

"We are working on a method to construct a functional conductive gate electrode that is stable when submerged in water, which is essential to bioelectronic interfacing where fluids are involved," Arthur said.

"We plan to incorporate biocompatibility studies to show that our electrodes aren't toxic to cells."

Yambem says Arthur's work has provided guidelines for future sensor designers to choose materials for transistor electrodes.

"These electrodes can be very important in the transistor function of devices we make.

"If we modify one of the electrodes, the property of the performance and of the device changes.

"It will either conduct electricity very well or not so much and it might be more sensitive or less sensitive."

Changing people's perceptions of physics

While Yambem spends much of her time working at the nanoscale, she also makes time for community-scale work.

She represents the physics discipline at university recruitment activities to encourage students to take up its challenges.

"Historically, physics is a field preferred by men, even during Marie Curie's era when it should have been more popular," Yambem said.

"During my undergraduate and masters degrees in India, about half of my class were women However, the female cohort was only about 25 per cent during my PhD studies in Houston.

"In the undergraduate physics units I teach at QUT, the number of female students is only around 25 per cent."

Yambem thinks the challenge lies in people's perceptions.

"I think people have a misconception that physics is difficult, that maths is difficult, but it can be very interesting.

"Physics is black and white. The science is either right or wrong, which makes decision-making easier. To me that is easier than writing literature or interpreting people's emotions, which I see as a grey area."

Students need to know they can create change

While the world has progressed in the 20 years since Yambem attended high school, she says students should be exposed to modern research outcomes from an early age.

"We need to popularise physics, maths and other STEM subject in schools from very early on because the number of students going into these fields reduces as they progress towards higher studies," Yambem said.

"Research on cancer drugs, treating dementia or schizophrenia, coming up with implanted devices that reduce pain or enhance communication in the spine. These things need to trickle down to students in a way they can understand so they are aware people who study fundamental science in high schools—someone in their situation—go on to change humankind.

"It's important to tell people that science and technology can bring big changes to people's lives.

"It's also important to tell them about famous science pioneers, modern scientists—not those from centuries ago—so they know research is a real career pathway they can choose."

Perhaps the fundamental nature of physics obscures its career pathways, but Yambem clearly sees great opportunities.

"Most people also ask what type of job they will get after studying physics," Yambem said.

"Physics is a very fundamental subject that allows you to transition to a range of jobs.

"It can take you into university, research, government, defence, weather, materials, data science, research and development for products, instrument companies, in the field collecting data and predictive work, in banks as quantitative analysts, and teaching. STEM teachers are very high in demand."

ABOVE Research student Joshua Arthur began his research career after completing capstone and vacation research projects.

WORLD-CLASS FACILITIES: Australia's new electron microscope for studying atomic processes in real-time

KEY CONTACT Professor Dmitri Golberg
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Central Analytical Research Facility
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Researchers in Australia will be able to perform unprecedented experiments with unique access to a state-of-the-art high-resolution transmission electron microscope, allowing them to view real-time processes at an atomic scale: trillionths of a metre.

QUT will install the first Australian-based TEM-ARM200F 'NeoARM' Atomic Resolution Transmission Electron Microscope manufactured by JEOL.

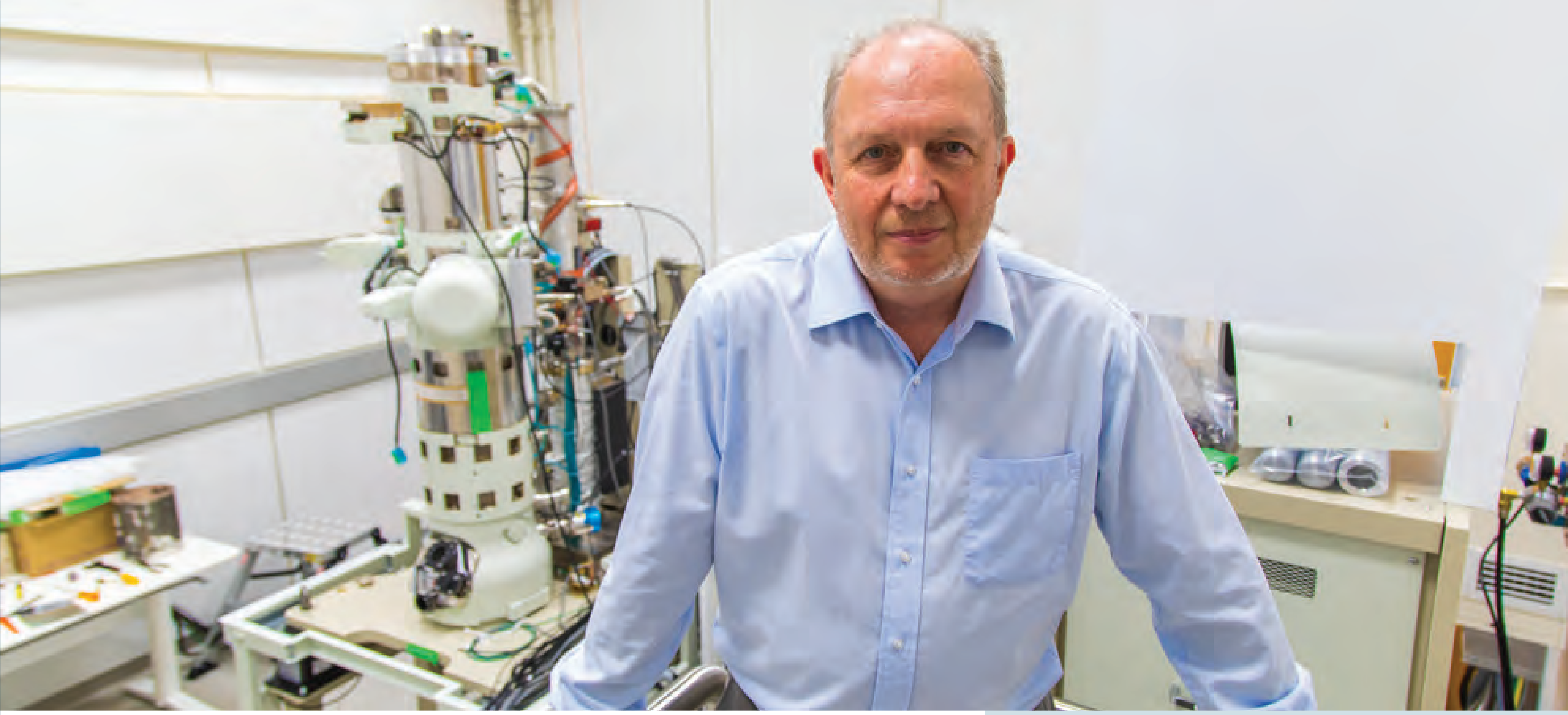
Australian Research Council Laureate Fellow Professor Dmitri Golberg, co-director of the QUT Centre for Materials Science, said the NeoARM would help advance understanding in materials science, physics, polymer science and bioengineering.

"The NeoARM will allow researchers to access high-resolution imaging of materials containing light elements and specimens susceptible to electron-beam irradiation," Golberg said.

"We also plan to achieve a very high level of a spatial resolution, better than 80 pm, or 80 trillionths of a metre, which means we can visualise the atomic structure and detailed crystallography, even individual atoms of any material.

"Its electron gun is modulated by a 10 MHz electrostatic beam deflector. In addition, a laser beam comes through a special holder to the sample site, so the dynamic experiments with a temporal resolution better than fractions of microseconds will be possible."

Researchers were already planning Australian-based time-resolved experiments involving catalytic processes and atomic changes under light, according to Golberg, who said the NeoARM's tuneable voltage would provide a rare opportunity to analyse beam-sensitive materials, like polymers and biosamples.



ABOVE Professor Dmitri Golberg with the first Australian-based TEM-ARM200F 'NeoARM' Atomic Resolution Transmission Electron Microscope being assembled at QUT. Installation began in September 2020 with operations expected to commence in early 2021.

Atomic resolution and aberration correction

The NeoARM's cold field emission gun (Cold-FEG) in combination with Cs corrector (ASCOR) enables atomic-resolution imaging at not only 200 kV accelerating voltage, but also a low voltage of 30 kV.

It is also equipped with an automated aberration correction system that incorporates JEOL's new algorithm for automatic fast and precise aberration correction.

This system enables higher-throughput atomic-resolution imaging even at low accelerating voltages.

It also includes a new scanning tunnelling electron microscope (STEM) detector that provides enhanced contrast of light elements and new imaging technique (e-ABF: enhanced ABF), facilitating observation of light-element materials.

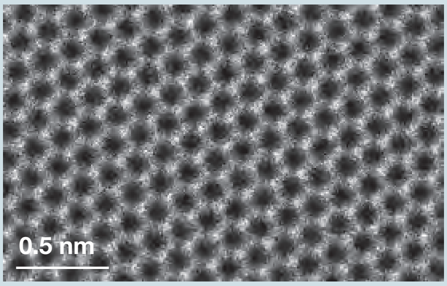
Specialist operators and technical support

Access to the NeoARM is managed through the QUT Central Analytical Research Facility, which will provide a dedicated and qualified technician and researcher to help or guide users.

Engineers from manufacturer JEOL will also provide technical support to QUT operators.

Specialist training is required to operate the NeoARM and can take more than six months to complete. Machine operators will need to pass induction before being permitted to use the device.

The NeoARM cost almost $4.7m with $2.7m funded through the Australian Research Council Linkage Program, $1.6m from QUT's Strategic Major Equipment Program, and $400k comprised of $100k contributions from The University of Queensland, Griffith University and the Australian National University and $50k each from The University of Sydney and the University of New South Wales.



Graphene is suggested to be the most useful material of the future—ultralight, superstrong and superconductive. It would be destroyed by the 200-300 kV electron beam voltages required to see its atomic structure with good spatial resolution. However, this atomically resolved graphene image was recorded via the NeoARM at 40 kV. It shows graphene's individual carbon atoms in a honeycomb arrangement.

The NeoARM will enable researchers to see the atomic structure of materials in order to understand possible defects, including vacancies and adatoms, which may negatively or positively affect the material properties.

CURIOSITY-DRIVEN RESEARCH

QUT Centre for Materials Science

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At the foundation of every material innovation lies a fundamental research effort pioneering concepts for real-world solutions.

Advanced functional materials are the cornerstone of modern society, impacting every aspect of our lives.

The QUT Centre for Materials Science is a fundamental scientific engine room for materials innovation.

Our research

Our researchers invent, design and optimise nanomaterials, polymers and metals to develop advanced materials with properties and functions tailored towards a specific real-world application.

- Alternative energy sources
- Longer-lasting batteries
- High-efficiency solar cells
- Reducing carbon dioxide in the atmosphere
- Next generation electronics
- Photoresists
- Molecular barcoding for product stewardship
- Biodegradable polymers
- Antifouling coatings
- Imaging agents for disease
- Light-activated catalysts

Innovation in materials design

Fusing our research strengths in soft-matter materials and hard-condensed matter, we design and develop advanced next-generation materials tailor-made to a specific function.

Matter-made-to-order

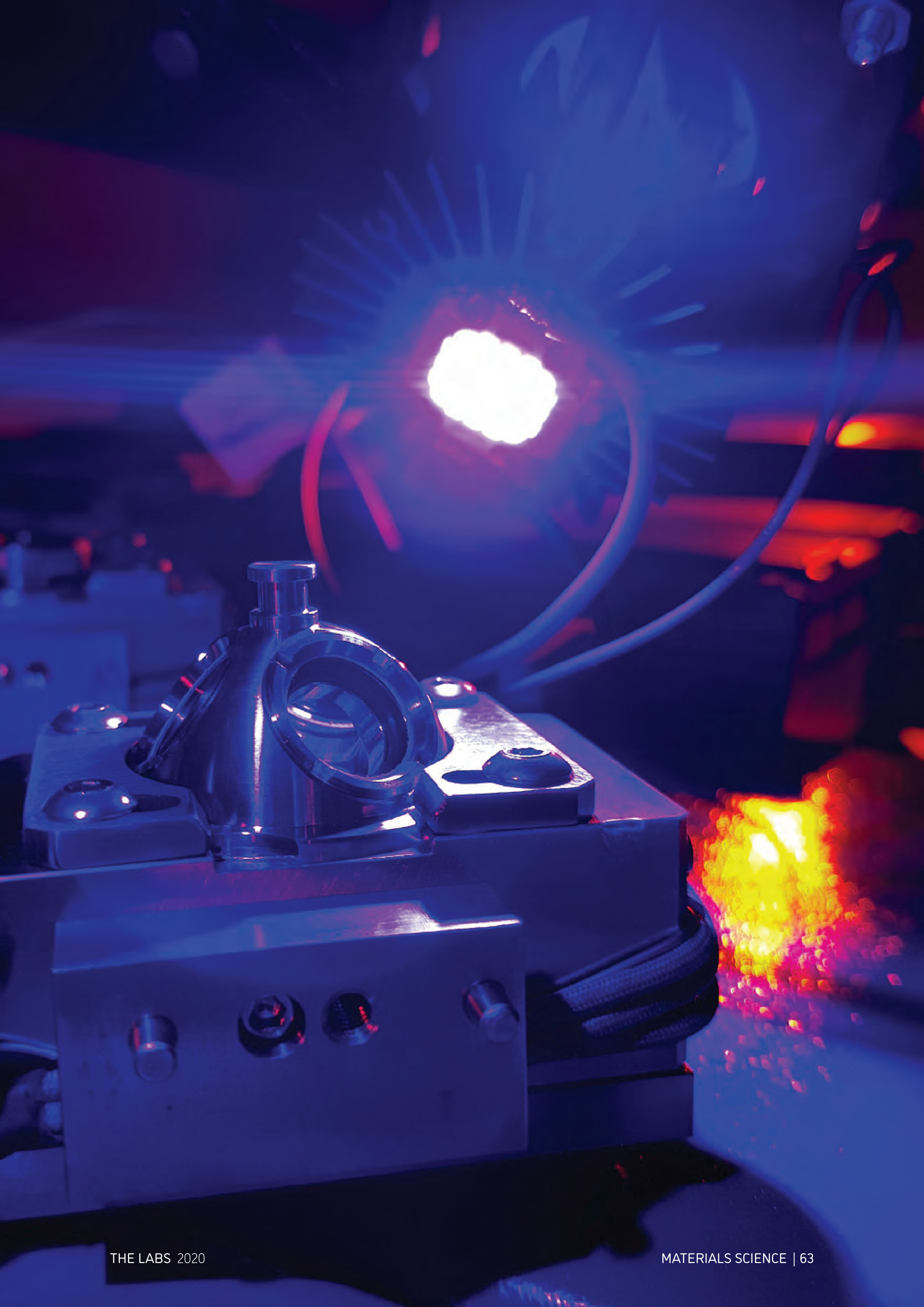
We design materials for specific functions using state-of-the-art computational platforms. Before producing materials in the lab, we design a range of target molecules via computer first then run simulations to determine the best candidates for a desired application.

Understanding materials through advanced analytics

Combining cutting-edge instrumentation and world-class technical expertise, we develop and deploy advanced technologies to understand the properties of materials at the molecular level.

We use established analytical techniques to identify and characterise our new materials, and also design and implement our own methods.

Our capability ranges from designing new analytical processes for analysing materials, to building entirely new instruments.



THE LABS 2020

ROBOTICS

QUT Centre for Robotics

Developing technology to better understand our world, work within our environments and benefit humanity.

Advanced automation through the Autonomous Combat Warrior program aims to transform a military vehicle from a tool into a teammate capable of not only recognising and traversing various terrain, but also understanding team commands.

TRANSFORMING TOOLS INTO TEAMMATES: Australian-made automated military vehicle capability with Rheinmetall

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QUT is leading major defence projects as part of Rheinmetall's new research and technology program to develop advanced Australian-made robotics and automated vehicle technologies.

Under the Autonomous Combat Warrior (ACW) program, QUT researchers are working alongside Rheinmetall's Australian, German and Canadian development teams, and research teams from Defence Science and Technology (DST) group, Commonwealth Scientific and Industrial Research Organisation (CSIRO), and the Royal Melbourne Institute of Technology (RMIT).

QUT and CSIRO teams will work together to develop systems that enable the new Australian Army vehicles to autonomously detect and recognise soldier commands, and traverse terrains to execute those commands.

Rheinmetall Defence Australia (RDA) Managing Director Gary Stewart said the program would lead the Australian development of next-generation automated combat vehicle technologies, which will be integrated into the family of Rheinmetall vehicle platforms.

"ACW's goal is to fundamentally change the way in which land vehicles support military operations by transforming a vehicle from tool to teammate to provide currently unachievable levels of soldier protection, support and tactical advantage," Stewart said.

"This will see the Australian development of the next generation of land vehicle systems' warfighting capability, with an emphasis on developing trusted automated systems that provide human-machine teaming and optional crewed control."

Cutting-edge technologies developed under the strategic alliance will support the 211 Boxer 8x8 Combat Reconnaissance Vehicles (CRV) replacing the Australian Light Armoured Vehicle, which has seen extensive operational service since its introduction in 1996.

Rheinmetall started delivering the new Boxer 8x8 CRV fleet to the Australian Army from 2019 under the Australian Defence Force $5.2b Land 400 Phase 2 program—Mounted Combat Reconnaissance Capability.

The significant upgrade of Defence vehicles with emerging technologies also includes a fleet of 3600 Rheinmetall MAN HX Logistics being deployed across Australia.

The vehicles are expected to support Army capability and enhance the safety, security and protection of Australian troops for the next 30 years.

These investments align with the Defence Strategic Update 2020 and the Force Structure Plan 2020, with future autonomous systems supporting sustained operations varying from peacekeeping to close combat.

Advanced terrain detection for machine decision-making

Through an Advanced Terrain Detection (ATD) project, QUT and CSIRO researchers will develop next-generation software for advanced terrain detection, called “I-Kit”. It will communicate with “A-Kit”, Rheinmetall’s Autonomous Kit software.

A-Kit is an autonomous driving vehicle capability currently integrated into Rheinmetall’s Mission Master vehicle. It provides the base software architecture for all future stages of the ACW research program.

Once developed, I-Kit integration would enable an autonomous ground vehicle to recognise different types of terrain, such as vegetation, rocks, sand, water and mud, according to Associate Professor Thierry Peynot, a chief investigator with the QUT Centre for Robotics.

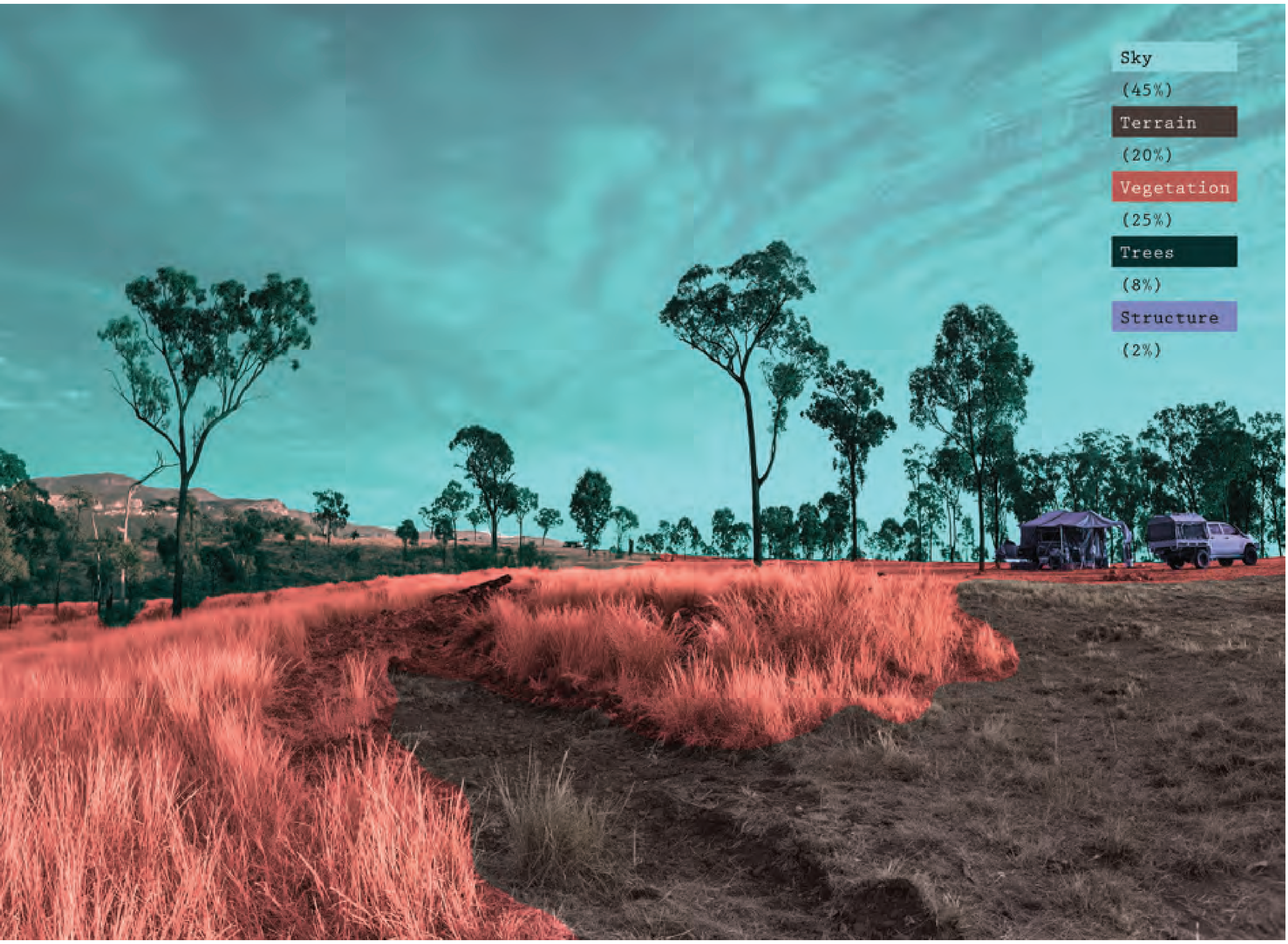
“Recognising terrain would be essential for machine decision-making based on the difficulty and possibility of traversing it, and the risk associated with that task,” Peynot said.

“We are developing methods to automatically analyse sensor data collected by a mobile platform to determine what types of terrain the vehicle is seeing ahead.

“Those sensors should include cameras and LIDAR, with possible additions to that setup as needed.”

When upgraded with I-Kit and other Australian applied research under the ACW program, Rheinmetall vehicles will be used to demonstrate the vehicle-agnostic and integrated payload capabilities of Rheinmetall’s Advanced A-Kit.

BELOW Artist’s impression of robotic terrain detection. The Advanced Terrain Detection (ATD) project is led by Associate Professor Thierry Peynot and Professor Michael Milford.



ABOVE The Vision Recognition System (VRS) project is led by Professor Clinton Fookes (LEFT) and Dr Simon Denman (RIGHT).

Recognising soldier actions and commands

Advanced automation through the ACW program aims to transform a military vehicle from a tool into a teammate capable of not only recognising and traversing various terrain, but also understanding team commands.

The Vision Recognition System (VRS), being developed using CSIRO experience in object detection and QUT expertise in human action recognition, will enable a vehicle to recognise simple soldier actions and commands.

“Rheinmetall is seeking to develop an autonomous vehicle capability where the vehicle could be integrated with a human team, which means responding to commands,” said Dr Simon Denman, senior lecturer with the QUT School of Electrical Engineering and Robotics.

“We are developing computer vision and machine learning software that will use vehicle-mounted cameras to detect people, their actions and other things of interest.

“The ideal outcome would be to embed a vehicle within a small squad and have that vehicle perform a designated support role without needing to be constantly controlled by another soldier.”

Researchers are currently investigating suitable vision recognition techniques and the integration of those with the vehicle platform.

In addition to the military applications, Rheinmetall will also explore civilian applications for the resultant technology as part of the ACW program.

“Generally, action recognition is broadly applicable to any situation that involves human-machine interaction,” Denman said.

“Action recognition would be applicable to any collaborative robotics project or video mining situations, for example, where we wanted to find particular actions in a large sample of video.”

Joining Denman and Peynot on the QUT research teams for ATD and VRS projects is Distinguished Professor Peter Corke, Professors Clinton Fookes and Michael Milford, Dr Harshala Gammulle, Dr Bilal Arain, Garima Samvedi, Melih Guenes Minareci, Dr Rune Rasmussen, Tim Hojnik, Ray Johnson, Andrew Keir and Michael Evans.

“The ideal outcome would be to embed a vehicle within a small squad and have that vehicle perform a designated support role without needing to be constantly controlled by another soldier.”

DR SIMON DENMAN

ABOVE The MILVEHCOE will support the design, manufacture and maintenance of current and new vehicles.

Humans in the loop

In the pursuit of new autonomous vehicle technologies, Rheinmetall is certain of one thing: humans will maintain ultimate decision-making control.

The company maintains that humans must retain the power of decision and therefore rejects fully autonomous weapon systems that deprive humans of the power to decide whether or not to use weapons against other humans.

It does not develop, manufacture or market fully autonomous weapon systems, according to Stewart, who said the ACW program will only focus on the automation of driving capabilities.

The five-year ACW program is funded by an $80m Technology and Product Development Fund established by Rheinmetall as part of its commitments to the Department of Defence Australian Industry Capability program to provide defence-related opportunities to Australian industry.

ACW OBJECTIVES

- Develop game-changing autonomous technologies in Australia.
- Leverage Rheinmetall global research and development efforts, and existing vehicle platforms and technologies to fast track the development of autonomous technologies.
- Develop a platform-agnostic Autonomous Kit (A-Kit) suited for integration into a variety of road and off-road military vehicles.
- Partner with the Australian research community and local industry with deep technical expertise to solve complex development problems.
- Generate a strong return on investment to the Commonwealth in the form of employment and sovereign robotics capability.
- Work with the Army to support its evaluation and strategy development for the use of autonomous vehicles.

New industry for Queensland and Victoria

The ACW program aligns with the Defence Strategic Update 2020, which seeks to introduce large numbers of autonomous systems to Defence.

Rheinmetall is fostering the development of this emerging high technology industry in Australia, with job creation a widely anticipated outcome of its research and development program.

After formally launching its first Australian research and technology program in February 2020, Rheinmetall moved into the new $170m Military Vehicle Centre of Excellence (MILVEHCOE) at Redbank, Queensland.

The MILVEHCOE will support the design, manufacture, testing and maintenance of current and new vehicles, as well as research jobs for partners like QUT and others.

Built in partnership with the Queensland Government, the MILVEHCOE is the cornerstone of the company's commitment to the Australian Industry Capability (AIC) Program and is designed to produce military hardware for the Australian Defence Force and for export.

The MILVEHCOE is a purpose-built facility for design and manufacturing with significant test infrastructure including a test track, electromagnetic compatibility (EMC) chamber, medium calibre (up to 35 mm) firing tunnel and prototyping workshop.

Capability across the new precinct runs from heavy manufacturing to a clean room for Rheinmetall's electronics division, as well as self-protection production capability for ballistic protection for ships and vehicles, and includes a sophisticated armour-manufacturing shop with state-of-the-art press to produce an array of composite ballistic materials.

Rheinmetall is fostering the development of this emerging high technology industry in Australia with job creation a widely anticipated outcome of its research and development program.

BELOW QUT researchers on the Advanced Terrain Detection and Visual Recognition System projects with Rheinmetall Managing Director and Research and Technology leads.

INNOVATION AT ARMHUB: Building better manufacturing processes through robotics

KEY CONTACT
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The Advanced Robotics for Manufacturing (ARM) Hub is a Brisbane-based not-for-profit company established by QUT and UAP (formerly Urban Art Projects) to bring sophisticated robotics solutions to manufacturing, creating and design.

Opening its doors in March 2020, ARM Hub brings together technologists, roboticists and designers to redefine the way industry and research can collaborate for growth.

Growing Queensland's robotics industry

ARM Hub was first envisioned when UAP needed to develop new ways of manufacturing large-scale public art projects.

"When an artist develops a concept for an installation, they often work on a small-scale prototype or create very detailed diagrams and instructions, but the actual manufacture of large urban art is done by manufacturers, not the artists themselves," explained Professor Jonathan Roberts, technical director and roboticist at ARM Hub and chief investigator at the QUT Centre for Robotics.

"UAP connected with QUT to explore ways of manufacturing these large pieces using robots.

"From these initial collaborations, it became clear that the connection between robotics, design and manufacturing was worth exploring, and so the Queensland Government, CSIRO and QUT came together to fund ARM Hub."

The team now works from their learning factory—a large, industrial space in Northgate, Brisbane—where there's room for researchers and industry partners to explore, experiment, and collaborate on new and exciting projects.

"South-East Queensland is a global hot spot for robotics, and QUT is uniquely placed to draw on the abundance of knowledge and talent emerging in the area," Roberts said.

Smarter production, better manufacturing

The key focus of the ARM Hub is collaboration between robotics innovators and industry.

"We want to work with companies to help them partially automate some of their processes to make life better for employees, make their manufacturing processes easier and help them explore new possibilities," Roberts said.

Robots are ideal to work in the manufacturing space, as they can perform repetitive, arduous or physically hazardous jobs without risking human safety.

The expert team at the ARM Hub customise off-the-shelf collaborative robots—smaller robots with human-sized arms—adding functionality, sensors and other attachments, as well as writing bespoke software solutions.

The team is made up of an ever-evolving group of specialists and technologists who are brought in as dedicated project resources.

"Our projects are so diverse that we need a range of skills over shorter time frames to work on solutions," Roberts said.

"At QUT, you can find an expert in pretty much any area you can imagine, so we can call on people who have the skills to contribute when we need them. It's an unusual model, but that agility is key to our responsiveness as a business."

Adapting to industry needs

"Not many Australian companies come to universities for help with projects," Roberts said.

"It may be perceived as too expensive or maybe small businesses, which are the majority of Australian businesses, don't think of university partnerships as a possibility for them.

LEFT ARM Hub CEO Associate Professor Cori Stewart and ARM Hub Technical Director Professor Jonathan Roberts inspecting milling robot arm at UAP.

BELOW Minister for Regional Development and Manufacturing The Hon Glenn Butcher with the ARM Hub team. **(LEFT TO RIGHT)** Glenn Butcher, Cori Stewart, Peta Portelli, Samuel Jesuadian and Professor Jonathan Roberts.


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"The ARM Hub is much more proactive about taking technology and ideas to industry—at all levels—to see how we can adapt it to their needs."

Since opening, the ARM Hub has been approached to develop solutions for medical technology, commercial laundries, painting businesses, injection moulding companies and traditional manufacturing companies.

"A lot of these companies need solutions for more niche or customised manufacturing problems," Roberts said.

"We're exploring whether robots can be used to make just one of something, where they've traditionally been used for mass-production.

"While robots can be expensive to set up and design, the technology driving them has matured and robotics programming has become more adaptable and agile."

This flexibility is key for any company wanting to invest in a robot for their practice: the robot should be able to focus on multiple tasks over a long period of time to provide a return on that investment.

"The great thing about the ARM Hub is that we don't have to keep reinventing the wheel," Roberts said.

"If we develop something for one project and have that piece of software or hardware ready on the shelf, we can then implement those solutions in other situations—we can take the work we've already done, put it in play and solve problems faster."

Working with agile, shared intellectual property requires levels of transparency and collaboration that aren't part of standard business practices today.

"It's a big cultural shift, but smaller companies need to work together to be competitive on a global scale," Roberts said.

"By building communities of practice between universities and the private sector, we're changing the narrative around collaboration and skill-sharing."

Medical technology innovation

The team at the ARM Hub recently collaborated with researchers from QUT's Medical Engineering Research Facility and manufacturer Olitek to create the OzVader ventilator, a smart piece of medical technology that will fill the gaps identified during the COVID-19 pandemic.

The ARM Hub team worked on a unique microcontroller system and user interface for the next generation of the ventilator, with the first iteration currently undergoing approval with the Therapeutic Goods Administration.

"We had to be agile and responsive with this work, and we had a team up and running within a day of the project leads approaching us," Roberts said.

"It goes to show how versatile our robotics skills are—those core ideas of programming and making machinery work effectively and efficiently can be applied to all sorts of fields."

LEFT Pick and place robotic demonstration by mechatronics engineer Amelia Luu during Minister for Regional Development and Manufacturing The Hon Glenn Butcher's visit to the ARM Hub.

RIGHT ARM Hub team outside the ARM Hub Learning Factory.

DRAWN FROM NATURE: International collaboration for bio-inspired robots

KEY CONTACT

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ABOVE Professor Michael Milford, QUT's project leader for the international AUSMURI program.

A new project has launched to develop the next generation of autonomous robot and vehicle technology, using the natural world as inspiration.

Over up to 5 years, researchers from the QUT Centre for Robotics will contribute to a $15m project to explore ways of creating autonomous systems with improved navigation and autonomy in unknown environments.

The Neuro-Autonomy: Neuroscience-Inspired Perception, Navigation, and Spatial Awareness for Autonomous Robots project is jointly funded by Defence Science and Technology and the US Office of Naval Research as part of the Australia–US Multidisciplinary University Research Initiative (AUSMURI) Program.

AUSMURI brings together experts from QUT, Boston University, Massachusetts Institute of Technology, University of Melbourne, Macquarie University and University of New South Wales.

Leading QUT's contribution to the project is roboticist Professor Michael Milford, deputy director at the QUT Centre for Robotics and chief investigator at the Australian Centre for Robotic Vision.

"The biological world is endless in the ways it can inspire us. Not just in terms of copying nature, but providing a foundation we can try to improve on," Milford said.

"We want to see what we can learn from how human and animal brains operate, and use that to make autonomous systems better, more capable and smarter."

Milford's previous research has focused on modelling the neuronal mechanisms underlying navigation in rats, so he's no stranger to looking at the living world for inspiration.

ABOVE QUT's AUSMURI team with Clearpath Jackal robot (LEFT TO RIGHT): Dr Tobias Fischer, Professor Michael Milford, Mr Marvin Chancán, Mr Stephen Hausler.

"Current robots and autonomous systems are typically good at a single or very narrow range of tasks, but fail at anything else. Animals and humans exhibit far more robust behaviours, and we can draw on this as inspiration to make autonomous systems more capable," Milford explained.

Roboticists will work with a team of the world's top neuroscientists to build deep learning and artificial neural networks to develop improved thinking and understanding in robotic systems. State-of-the-art new sensing technology like event cameras, which see visual change rather than colour, will also be used.

"We can then validate and refine the models we develop using our robots, creating more sophisticated navigational systems," Milford said.

Milford has dedicated his career to robotics research focused on perception and navigation, making him a perfect fit for the project team.

While a significant part of Milford's previous work has focused on real-world applications for autonomous vehicles, the AUSMURI project represents an important opportunity to explore fundamental robotics research.

"There's a lot of merit in tying some research funding to concrete outcomes, but we also need opportunities to explore more fundamental concepts, take risks and push the boundaries of science," Milford said.

"Sometimes the breakthroughs are astounding and have huge implications for the future of robotics. This project is set up to do exactly that."

The project builds on QUT's significant capabilities in robotics research.

"Our involvement in this project will further build our reputation as a leading centre for robotics research in Australia and around the world," Milford said.

"The biological world is endless in the ways it can inspire us. Not just in terms of copying nature, but providing a foundation we can try to improve on."

PROFESSOR MICHAEL MILFORD

REPLICATING HUMAN PILOT VISION: Maths model the key to aerial detection system

KEY CONTACT Professor Jason Ford
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QUT researchers have used a complex maths model to develop an algorithm that enables unmanned aerial vehicles (UAV) to replicate a human pilot's ability to visually detect aircraft at a range of more than 2 km.

Professor Jason Ford, who was awarded the inaugural Australian Defence Industry Award of Academic of the Year in 2019, said developing the visual detection system had tackled the key barrier to fully achieving the global commercial market of unmanned aerial vehicles.

"We've been working on this problem for 10 years and over that time 50 people or more have been involved in this project," Ford said.

"We are leading the world in solving the extremely challenging problem of replicating the role of a pilot's eye.

"Imagine you're observing something from a cockpit and it's hidden against the clouds. If you watch it over a period of time, you build up confidence something is there. The algorithm does the same."

The advisory for human pilots is that they will need at least 11.4 seconds to commence an avoidance manoeuvre once they visually detect another plane or other aerial vehicle.

In the past decade, the system has evolved through a range of testing including on aircraft and on UAVs.

The QUT researchers developed the algorithm based on a mathematical model called the Hidden Markov Model (HMM).

HMMs were developed in the 1960s and allow people to predict unknown or hidden variables from observed information.

Ford said although most people outside of the maths community would not have heard of HMMs, they would have benefited from its many applications in economics, neuro-biology and telecommunication, citing examples as broad as DNA sequencing to the speech recognition systems used by smart phone digital assistants.

The algorithm used in the UAV object detection system was developed by Professor Ford and colleagues Dr Tim Molloy, Dr Jasmin Martin and others.

"The algorithm boosts the weak signal while reducing the surrounding signal noise," Ford said.

One of the major challenges in developing the sense-and-avoid system for unmanned aerial aircraft was to make it small enough to be able to be carried on a UAV.

The breakthrough is the latest step after a series of related research projects in the past decade, including the Smart Skies Project and Project ResQu in collaboration with Boeing Australia and Insitu Pacific.

Testing commenced in 2010 with flights to collect data to start working on the project, and in early 2014 a breakthrough proof-of-concept flight proved a system in a UAV was able to detect another aircraft using vision while in flight.

"Boeing and Insitu Pacific have valued the ongoing collaboration with QUT and Professor Ford's team," said Brendan Williams, Associate Technical Fellow, Airspace Integration for The Boeing Company.

"The algorithm has been evaluated and matured in regular flight tests with strong positive results, and we are looking to transition its use as a baseline technology in regular Beyond Visual Line of Sight operations."

The research has focused on improving the performance, size and cost of the technology to improve the commercial feasibility of the system.

Ford said the ultimate aim of this research was to enable UAVs to be more easily used in general airspace for commercial applications.

BELOW Professor Jason Ford

MACHINE LEARNING: Student findings could guide vision-based detection research

KEY CONTACT Dr Jasmin Martin
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Dr Jasmin Martin is giving engineering students first-hand project experience that could guide future research on vision-detection technologies.

ABOVE Dr Jasmin Martin supervises students working on vision-based aircraft detection solutions.

Martin supervises final-year students for their capstone project on vision-based detection.

The project is closely related to her work on an algorithm that enables unmanned aerial vehicles (UAV) to detect aircraft at a range of more than 2 km.

“In my research, I’ve taken a control systems approach to detecting aircraft in image sequences, but students take a machine and deep learning approach, which is something I’d like to investigate more,” Martin said.

“Students work on detecting a medium-sized fixed-wing aircraft at distances ranging from about 500 m to 3 km.

“They investigate spatial and temporal aircraft behaviour to learn what the aircraft looks like to a vision-based system, and how it approaches and moves in an image sequence.

“Findings from these student projects could be used to guide research direction.”

Each year, students have access to previous students’ findings and, according to Martin, have made significant progress towards aircraft detection.

Detecting more detail in images

This year, mechatronics student Somayeh Hussaini is working on the vision-based aircraft detection problem under the co-supervision of Martin and Professor Jason Ford from the QUT Centre for Robotics.

She is developing a machine learning model that uses deep learning, the same behaviour a human brain uses to function.

“Deep learning is a technique where artificial neural networks are able to learn data features from large amounts of data,” Hussaini said.

“Deep learning models are inspired by the complex dynamic characteristics of our brain. Larger network depths can give us more accurate predictions.

“In terms of identifying images, that means we can detect more detail and identify or accurately predict aircraft in images as small as possible.”

A machine learning model can be trained to identify patterns in images and make predictions using the deep learning technique.

“If I gave a machine learning model lots of pictures of human faces and trained it to identify patterns that divided them into genders, it would then be able to predict the gender of a human if I gave it a new image,” Hussaini said.

“In this case, we are training the machine learning model to identify and track an aircraft when it’s a great distance away — only a few pixels on the screen — and surrounded by clouds.”

Because of the complexity and time needed to create machine learning models, Hussaini is using an existing set of algorithms proven to be useful in detecting small objects in sequential images.

She started by using synthetic data: images in which researchers added aircraft to synthesise the most ideal scenario of visible aircraft.

“By having a bounding box around the aircraft in sequential images, I can train the machine learning model to identify and track its movement so that it can predict the location of the aircraft in unseen video sequences,” Hussaini said.

“In the future, when an aircraft takes off it will start capturing its surroundings and continually detect other aircraft.”

Next, Hussaini will use real data — video sequences of aircraft in clear and cloudy conditions — sourced from researchers who have published their datasets.

“Researchers are always publishing papers on new ways to improve the model so it can predict more accurately,” Hussaini said.

“These could apply to everyday products like vacuum cleaners, not just aircraft, but would be very useful for UAV to operate autonomously while protecting other aircraft through early detection and avoidance.

“My project is only on detection at the moment, but the next step would be trying to implement a system to avoid other aircraft.”

Mechatronics students have a choice of combining mechanical engineering with electrical engineering or computer science units.

Hussaini focused her studies on mechanical and software engineering while holding multiple scholarships and working with the university as a student ambassador helping high school students learn about STEM.

From her second year, she has also worked as a software engineering intern for global technology company Deswik, but is yet to decide if she will take a graduate position in industry or continue with a career in research.

“If I have more time in research, I would like to explore algorithms more to see how I can improve existing models,” Hussaini said.

BELOW Mechatronics student Somayeh Huissani (FRONT) is developing a machine learning model to detect aircraft. Pictured with co-supervisors Dr Jasmin Martin and Professor Jason Ford.

Robotic kangaroo leg was a springboard to research

Martin herself followed the path to research after her capstone project to develop a robotic kangaroo leg before completing her mechatronics engineering course.

"I really enjoyed my final-year project and wanted to continue the research. I was also a sessional academic for about three years during my undergraduate course and wanted to keep teaching," Martin said.

After graduating, Martin started her PhD studies and joined an industry-funded vision-detection project led by Professor Ford and Dr Tim Molloy from the QUT Centre for Robotics.

Since then, she has helped develop a new "quickest detection" mathematical theory and design algorithms that identify aircraft among visual clutter like clouds.

"Until we have adequate sense-and-avoid systems, there is a barrier to flying UAV in national airspace," Martin said.

"The final safety layer for unmanned aircraft is a sense-and-avoid system, which is the implied regulatory requirement that a UAV has to be able to sense and avoid a collision threat either as well as or better than a human pilot."

The right teacher can define your career pathway

Among her supervisory and research work, Martin also teaches first-year students the foundations of electrical engineering and third-year control engineering through the QUT School of Electrical Engineering and Robotics.

If not for her own teacher explaining maths in just the right way, Martin says she may not have found herself on the path to engineering or research.

"I was really lucky in high school. I had an awesome maths teacher who explained concepts in a way that I understood easily, and encouraged me to do engineering," Martin said.

"I really enjoy problem solving, and that's what I liked about my mechatronics course. There were so many projects in which we were just given a goal and had to find the solution on our own."

While some students can struggle with not having defined outcomes to problems, Martin believes that engineering training teaches them how to approach questions and find answers.

"Learning how to find answers is not just a part of your degree but how you want to live your life. You can't just rote learn—you have to actually understand problems," Martin said.

"Deep learning models are inspired by the complex dynamic characteristics of our brain. Larger network depths can give us more accurate predictions.

In terms of identifying images, that means we can detect more detail and identify or accurately predict aircraft in images as small as possible."

MECHATRONICS STUDENT, SOMAYEH HUSSAINI

INNOVATION IN NAVIGATION:
Smarter robots, at your service

KEY CONTACT Associate Professor Niko Sünderhauf
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Teaching robots to understand where they are and how they can interact with their environment is the key to unlocking the next generation of automated service systems.

Associate Professor Niko Sünderhauf has been awarded a competitive and prestigious Amazon Research Award for 2020, receiving $120k in funding to investigate robotic models for navigation, manipulation and interaction.

Sünderhauf is a leader for the visual learning and understanding program at the QUT Centre for Robotics. His research focuses on how robots can perceive the world around them, understand the objects they see and use that information to complete tasks.

Sophisticated semantics

The new project, funded by the Amazon Research Award, will build on existing methods of robotic vision and navigation to make them more sophisticated and capable.

"Current robotic algorithms use camera images to create a map of their environment, but this only supports a very simplistic understanding of objects in the environment," Sünderhauf said.

"Robots today can get a good understanding of where things are around them, but not what these objects are, and what the robot or humans could do with them. This simplified model of the world isn't sophisticated enough to inform higher levels of learning, often making it impossible for a robot to learn complex tasks."

Sünderhauf is investigating the possibilities of object-oriented semantic mapping to develop more meaningful maps of environments that robots can navigate and interact within.

"Object-oriented semantic mapping means that robots have learned to detect and distinguish different objects, and can create a map of all the objects in an environment, each with its own location, type and functionality," Sünderhauf explained.

While the robot still uses the camera to see, its interpretation of the environment is based on a deeper understanding of objects.

"Rather than using camera data to recognise visually what a singular fridge in a particular environment looks like, the robot will create a deeper understanding of what a fridge is, how it acts, what's kept inside it and how to open the door—things like that. When it moves into new environments, it will be able apply that knowledge to unknown settings."

Good robot!

Once the robot begins to formulate ideas of semantic meaning for objects within its environment, researchers have to devise a way to help the robot learn appropriate interactions with those objects.

Optimising a robot's interactions is managed by rewarding correct behaviour, using a process called Deep Reinforcement Learning.

"It's probably not that different from training a dog," Sünderhauf said.

"We're providing a reward signal when the robot exhibits correct behaviour and interactions in the environment. The robot is programmed to optimise its behaviour to seek as many reward signals as it can, so that reinforces correct actions.

"Investigating the limitations and strengths of Deep Reinforcement Learning in this context is a key focus of our project."

Mapping environments

Sünderhauf and his team are creating rich, descriptive maps of environments called graph-based maps to help the robots interpret their surroundings.

Unlike traditional maps with roads and landmarks, these maps are made up of nodes and links, coming together to describe an environment and its contents.

"Nodes in the graph represent objects, like a sink, a pen or a knife. Other nodes represent locations in the environment the robot can navigate to. The links between nodes represent potential interactions, like how a robot could reach them from certain positions within the environment," Sünderhauf explained.

These graph-based maps are the key to robots being able to interact more robustly in an environment.

"When the model of the environment is more detailed and more meaningful, the robot can learn better, act faster, and function more efficiently and successfully within the environment as its understanding of that environment grows," Sünderhauf said.

While the team are preparing the maps and programming them into the robotic models initially, robots would be able to use simultaneous localisation and mapping (SLAM) techniques to build these maps themselves in the future.

"SLAM is when a robot builds a map inside its 'brain' as it moves within an environment, while also localising itself with the help of the still incomplete map," Sünderhauf explained.

"The robot can use the map to keep track of where objects are and how to move around them as it goes."

Robo-butlers of the future

Sünderhauf's project is focused on robots in domestic settings, completing tasks like helping clean the house, finding lost objects or fetching a delivery from the front door.

"Beyond that, it can have a huge impact on specialised care robots, like those working in hospitality, assisted living or aged care. It'll be really useful for logistical robots, like delivery robots that have to interact with partially unknown environments to complete their task, including navigating gates and doors," Sünderhauf said.

It could also mean that robots who interact with humans in logistics or manufacturing will perform better, as they will be faster to train, better at understanding different appearances and ultimately safer.

The key challenge for Sünderhauf and his team will be taking the robot from simulated test environments to unknown physical test environments.

"Right now we are using quite a rich simulation environment. The robot can do things like open a fridge, take out a loaf of bread, and slice it, and then put the bread in a toaster," Sünderhauf said.

"Simulation is great for our research because it allows robots to do things that are currently hard for them to do in the real world, like articulation and grasping."

Other research teams at QUT are working on projects dedicated to grasping arms and robotic manipulation, and Sünderhauf is excited for the opportunity to develop his project in parallel.

Where to from here?

Over the course of this one-year project, Sünderhauf and his team will build on the proof of concept that won them the Amazon Research Award.

"Our proof of concept demonstrated that the robot could find objects, like house keys or a television remote, in a simulated environment, using this graph-based reinforcement learning," Sünderhauf said.

"Our initial investigations worked across both training and unseen environments, so we know that what we want to do is possible."

Sünderhauf is enthusiastic about the opportunity to develop key fundamental research in robotics.

"We're looking at creating a whole new generation of robotic learning. We're very excited to see where this takes us."

> Sünderhauf is investigating the possibilities of object-oriented semantic mapping to develop more meaningful maps of environments that robots can navigate and interact within.

FIND THE LION:
Robotic navigation and wayfinding

KEY CONTACT Dr Ben Talbot
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Robotic systems are becoming better at navigation all the time, especially when integrated with GPS and other supporting technology—
but how can robots find their way around unmapped, unknown spaces, like office buildings, university campuses and hospitals?

Dr Ben Talbot from QUT's Centre for Robotics has developed wayfinding robots that can read signs, understand directions and contextual clues, and navigate complex environments relying on cues and signposts rather than detailed maps.

Choosing a novel way to test their systems, Talbot's team set up an abstract zoo on the floor of the robotics lab, and asked the robot to find animals around the space.

Mapping and navigating from cues

Researchers tested navigational tasks with robot and human test subjects to benchmark the robotic system's performance against innate human navigation and wayfinding skills.

"We used AprilTags—similar to QR codes—that the robot could scan and translate into navigation cues, and humans used a mobile app that could access the same directions to ensure there was a level playing field," Talbot said.

"Both robots and humans were given a hierarchical model to ensure consistency in contextual understanding—like knowing that lions might be with the other African animals."

By engaging with directional cues ("to the left", "past the giraffe", "behind the penguins"), the robot outperformed human test subjects who attempted the task using the same information.

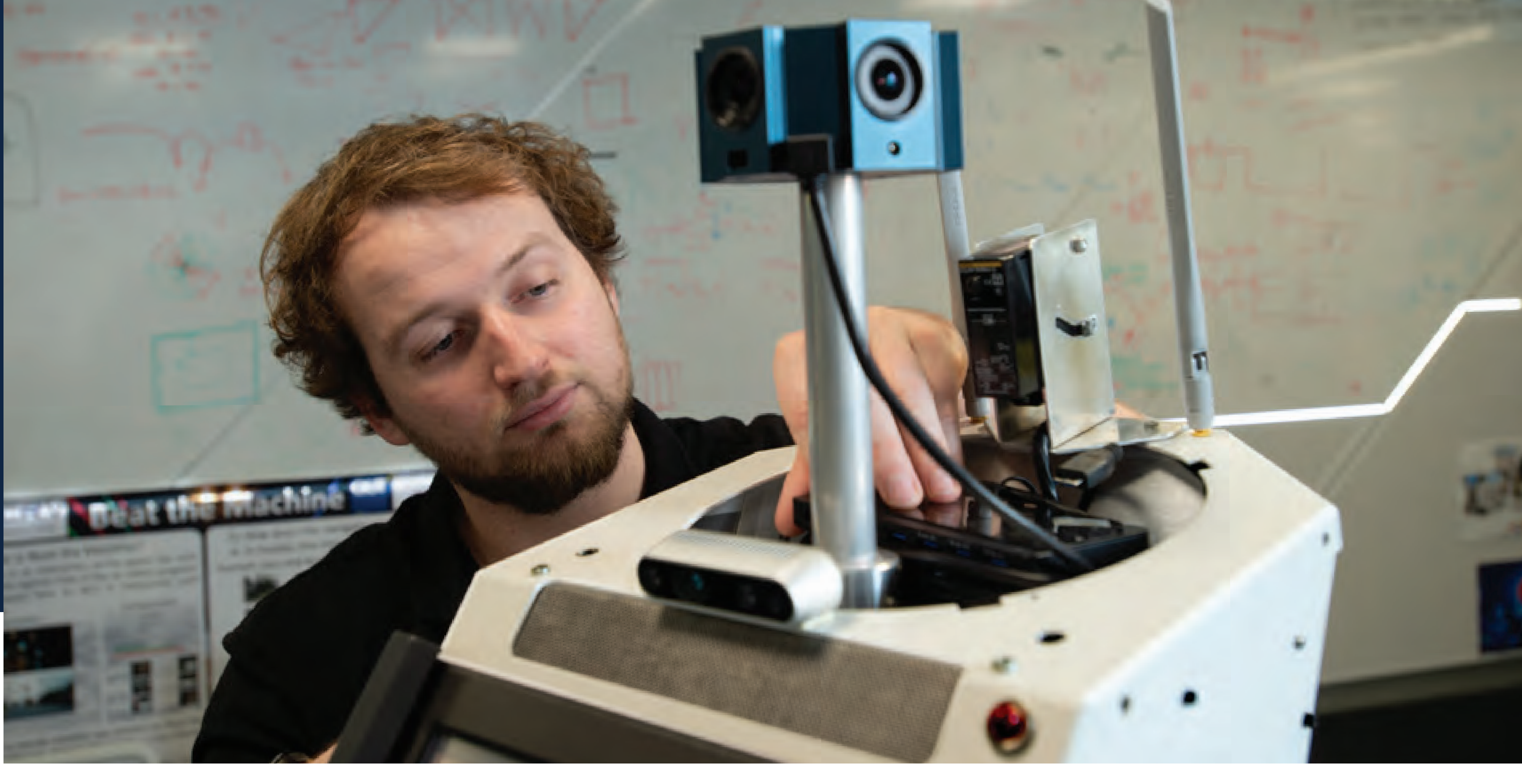
Much of the existing mapping and navigation technology relies on the fact that robots base their wayfinding decisions on prior knowledge, or on maps and models that have been pre-uploaded to the system.

"We don't work that way as humans—navigation cues are central to how humans operate in built environments, so our research focuses on how we can replicate that within robotic systems," Talbot explained.

"For example, someone can ask you to meet them in their office. Even if you've never been there before, you have ways of finding it, and you certainly don't need someone to hold your hand or walk you through the environment to understand how to find a new place."

A map that moves as you learn

The navigation process is built around a novel navigation tool called the abstract map, which embraces the use of symbols in navigation cues for describing relationships between places: directions like down, past or behind, or visual symbols like an arrow or a pointing gesture.



ABOVE Dr Ben Talbot programs an Adept GuiaBot robot to navigate using an abstract map.

There's a big difference between "down the hall" and "down the highway", though, so the abstract map is founded on a malleable spatial model, which gives the robot the flexibility to change and reconfigure its understanding of these symbols as it interprets them in the environment.

"The malleable spatial model is based on a system of simulated spring dynamics that can be stretched, pulled and adapted as the robot sees more information and builds its modelled understanding of the location," Talbot explained.

"The spring is an analogy here: just like a spring can be pushed, pulled and moved around as you add more forces to the system, the new observations the robot makes as it explores impact the spatial model that it's building.

"If we say something is 'down the hallway', the robot uses some default parameters to take an initial guess at its location, but there's a lot of ambiguity around what 'down' could actually mean in relation to the goal location.

"The spring places the estimated location in a flexible way, so if the robot reaches the location and the goal isn't there, the spring can be stretched in both distance and direction—this enables the robot to explore further and widen the scope of the navigation."

Concrete instructions around distance and direction add tighter springs to constrain the guessed location, which gives them a higher priority than more abstract directions like "down", "past" or "up the road".

These spatial models could then be shared between different robotic systems to contribute to a flexible navigational knowledge base across systems.

Navigation in the real world

The biggest challenge for robots reading navigation cues out in the real world is the context—understanding the cue in relation to the environment.

"Imagine if a robot goes past someone wearing a shirt that says 'I love New York': how does the robot know that it's just an article of clothing and not a sign that it's suddenly in New York City?" Talbot said.

"We had to be mindful of this in our experiment, and set it up in an abstract way and with limited peripheral cues so that humans couldn't get extra contextual information about where the animals were."

The research formed part of an Australian Research Council grant to explore navigation in unseen built environments where GPS can't support wayfinding.

"It's impractical to map the world down to that granularity," Talbot said.

"Humans can get where they need to go without too much fuss, so why can't we make robots work in a similar way?"

NAVIGATION, CREATION, INNOVATION

QUT Centre for Robotics

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Robotics is changing the landscape of our lives. Our research team at the QUT Centre for Robotics is prepared to meet the challenges, build the knowledge base and discover the answers that this ever-growing field of research demands.

Our centre is one of the largest robotics research groups in Australia. We're forging key links with Brisbane's strong start-up culture, emerging and established robotics companies, and the nation-first robotics cluster Queensland Robotics.

We're equipped to bring robotics solutions to a broad range of applications, and our team of experts are constantly innovating to bring about real change. Our strong partnerships with industry and government allow us to address our partners' challenges—now and into the future.

Our research

Our projects focus on:

- aerospace autonomy
- agriculture
- autonomous vehicles
- bio-inspired robotics
- defence
- infrastructure
- marine and environmental robotics
- medical and healthcare settings
- mining
- robotic grasping
- vision learning and understanding.

Making the right decisions

Robotic decision making is at the cornerstone of safe robotics implementation. We're working across multiple platforms and environments to ensure our shared spaces—from roads to the skies—are safer, more efficient and accessible to all.

Wayfinding, vision and understanding

Moving around an environment is a critical skill for autonomous systems. When a robot can perceive and interact with its environment, it can begin to function within it. We're developing solutions for localisation, mapping, wayfinding and navigation for a range of autonomous applications.

Interacting with the world around us

Our researchers are working on smart robotics systems that can interact with objects in their environment. From aquatic robots that fight back against invasive starfish, to robotic arms that can grasp and raise objects, we're pushing the boundaries of robotic interaction.

“Working as a team provides its own reward, especially in these times of limited funding. Sponsoring the academic success of others is not something to be feared.”

PROFESSOR CHRISTOPHER BARNER-KOWOLLIK

ACTIVELY SPONSORING YOUNG RESEARCHERS: The long game to independent research is a team play

Professor Christopher Barner-Kowollik
Australian Research Council (ARC) Laureate Fellow
Deputy Vice-Chancellor and Vice-President (Research)
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Universities play an important role in producing ground-breaking, internationally competitive research that is transformative for our societies. While universities are not necessarily driven by the market, our contribution to the industrial development of Australia and the world is of critical importance.

Growing a strong and diverse university research capability is a long game that can play out over decades. Strategic mentoring, active sponsorship and teamwork can cut a path for early career researchers and leads to a prosperous research community.

Actively sharing expertise and sponsoring the next generation of researchers is critical to increasing the rate of academic success. It also contributes to a collaborative school of thought that seeks, finds and benefits from new opportunities.

Game strategy

Active sponsorship is a mentoring strategy that does not leave success to chance.

Senior academics must share knowledge and foster trust: they teach young postdoctoral researchers who wish to pursue an academic career how to run a successful research group, lead a class and take on the responsibilities of their role.

Academia is a hard road and not for everybody; it can mean years of uncertainty and movement between institutions and often countries.

The payoff is the academic freedom to follow your passion in a research direction which often leads to new, ground-breaking technologies that overcome fundamental challenges in our society.

Using active sponsorship, three of my postdoctoral fellows have obtained professorial positions through my laboratory at the Karlsruhe Institute of Technology (KIT) in Germany.

At QUT, two of my postdoctoral fellows have successfully obtained Australian Research Council (ARC) funded fellowships and begun their journey towards successful independence with one reaching independence through both KIT and QUT.

Together, we came up with a game plan for their success.

Based on my own experience in an actively sponsored environment at the University of New South Wales (UNSW), and with almost two decades of experience in mentoring the next generation of research leaders, I will outline the key elements of active sponsorship.

Team selection

Choosing team players who are willing to put in the hard yards is the most important component of any active sponsorship relationship.

When choosing mentees, I am transparent about the failure rate of seeking a leadership position in academia and the work ethic required to become successful.

Sponsoring someone's career progression means I also need to work hard to ensure that my mentees receive the support specifically tailored to their needs.

Early career researcher success is not achieved by meeting a mentee every 6 months; a mentor must be available to support their protégé on a weekly basis.

Sponsorship also ensures no one is left behind, especially when candidates reach the point in their lives when they want to start a family.

To achieve long-term success, you must consistently track the needs of your sponsored researchers and continually look after their welfare.

Look for openings and pass the ball

Active sponsorship means strategically positioning your postdoctoral fellows to advance in their career by giving them opportunities to demonstrate and develop their academic independence.

Supporting your mentee to obtain a government-funded fellowship is critical to their ability to pursue their own research and publishing avenues. Your support means they can do this while remaining embedded in the larger research activities of a senior academic's research group.

It's all about the team effort and enabling other people's success. Key elements of active sponsorship that you can follow include:

- Work with your mentee to clearly define joint and independent areas of research. Embrace the mentee's skill set to open a new research field for the group, creating a new focus area and making the mentee's work visible and independent.
- Make sure the mentee is involved in your ongoing projects and PhD supervision to provide opportunities to publish widely in the early phases of their road to independence.
- Provide opportunities for your mentee to hold corresponding author positions on publications early on, but be sure to teach them what it means to take on that responsibility in terms of student supervision load and research project leadership. Let your mentee submit the manuscript to build a relationship with editors in chief and editorial boards.
- On selected joint work, step back from authorships. Never co-author a primary data paper in your mentee's research space, regardless of how much you have advised them.
- Recommend your mentee for invited speaking slots at conferences. When and where suitable, transfer your invitation to your mentee, explaining to the conference chair that you would be proud if they represented the research group.
- Foster future opportunities in the industrial space by including your mentee in specific industry engagements. The mentee will learn from your negotiation strategies with industry partners and can grow a network outside the academic realm. Share all credit for that relationship equally with your mentee.
- Actively share your academic leadership experience. While an early career researcher is well equipped to lead projects on a scientific level, they still need to develop strategies to successfully lead a team of individual researchers. Joint supervision of PhD projects is an excellent opportunity for your mentee to actively learn from your leadership, especially if you make your thought process and decision-making rationale transparent.

Building a team culture

You become a leader when you are able to advance the careers of others.

Professors who have already been promoted to the top of their career are in a good position to drive the culture of active sponsorship and allow young researchers the opportunity to pay it forward one day.

It is difficult to formalise active sponsorship because it is a cultural practice, and researchers need to grow up with it.

> Reward and recognition for mentoring someone into a fellowship position has to be embedded into the fabric of our university's culture.

However, a culture of active sponsorship intrinsically leads to very tangible wins, as the benefits of engagement, support and shared success come back to you and your institution in time.

Success breeds success

Working as a team provides its own reward, especially in these times of limited funding. Sponsoring the academic success of others is not something to be feared.

Postdoctoral researchers who can grow their networks and influence also become a natural fit for joint grant proposals and international collaboration when they achieve their own professorships.

Active sponsorship can also create prestigious opportunities for senior researchers.

Professors who actively sponsor are more likely to achieve the highest level of fellowships, centre directorships and other senior positions.

To ensure the continued growth of our research communities, every professor should have a strong network of peers who come from this active sponsorship school of thought.

Your mentee's success is everyone's success.

PAYING IT FORWARD:
Active sponsorship in action

PROFESSOR CHRISTOPHER BARNER-KOWOLLIK

Professor Christopher Barner-Kowollik has used the active sponsorship model to mentor postdoctoral researchers to professorship through his soft matter materials laboratories at KIT and QUT.

Research groups with a successful active sponsorship model in place foster young researchers into leadership positions and grow a mutually supportive research community.

MENTEES

PROFESSOR TANJA JUNKERS

Polymer Synthesis, Flow Chemistry, Machine Learning and Polymerisation Kinetics

Monash University

PROFESSOR GUILLAUME DELAITTRE

Organic Functional Molecule, Functional Polymer Synthesis and Nanomaterials

University of Wuppertal

PROFESSOR EVA BLASCO

Functional Polymeric Materials

Heidelberg University

ASSOCIATE PROFESSOR JAMES BLINCO

Macromolecular and Materials Chemistry, Organic Chemistry

QUT

DR HENDRIK FRISCH

Discovery Early Career Researcher Award (DECRA) Fellow

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