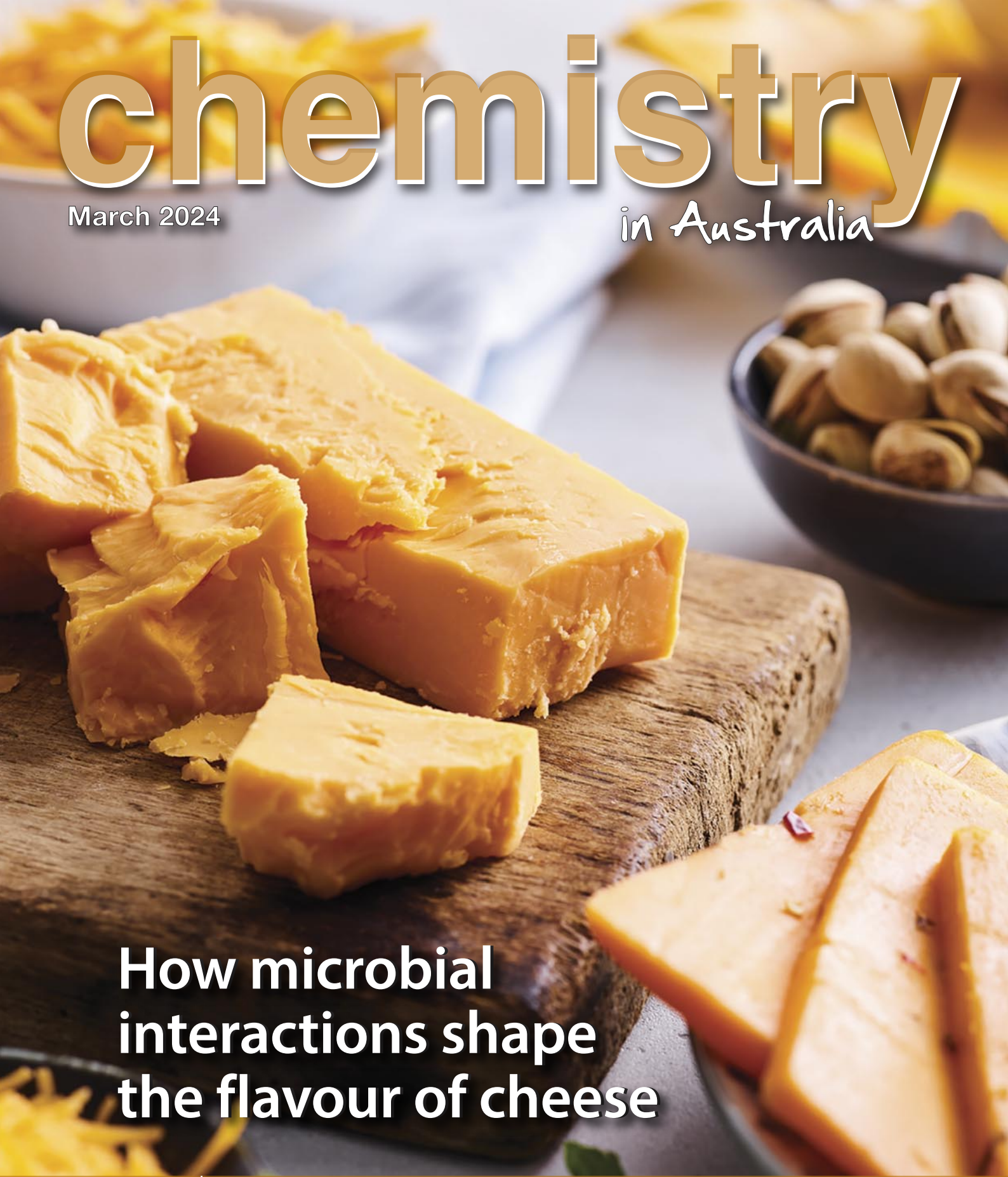
chemistry in Australia
March 2024



How microbial interactions shape the flavour of cheese

- Defence Bill limits on research collaboration
- The skills bottleneck facing renewables
- The chemistry of blooming Easter chocolate

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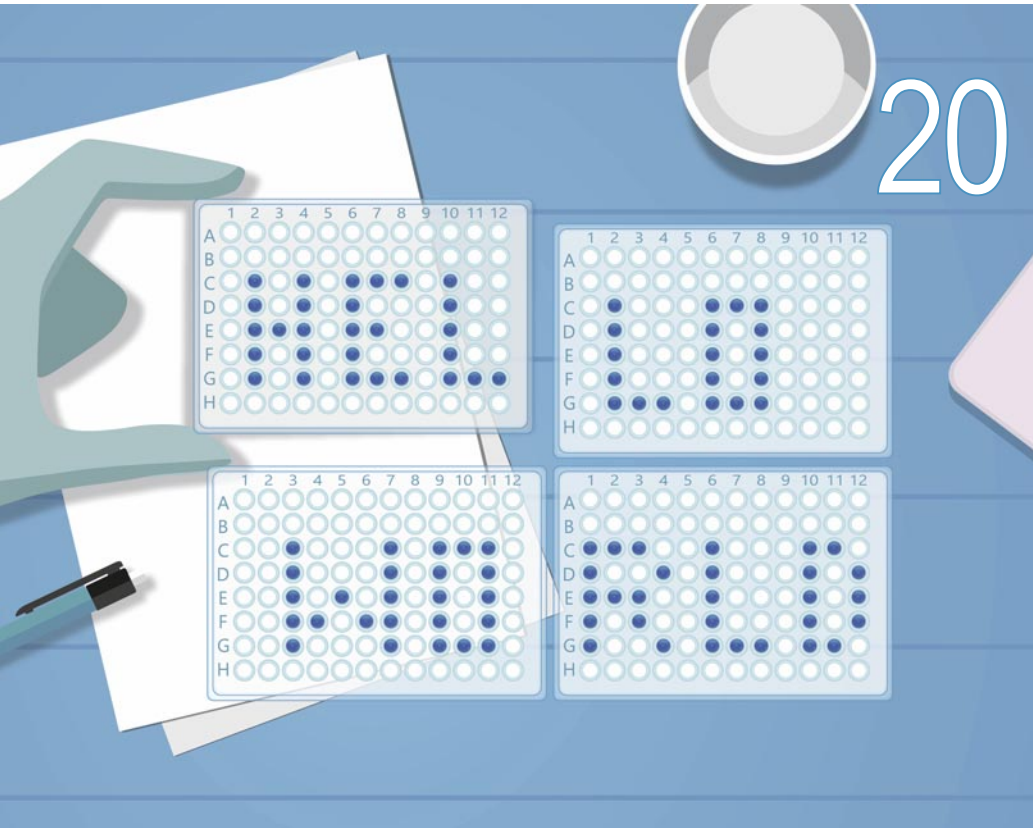
chemistry in Australia

March 2024

cover story

How microbial interactions shape the flavour of cheese

A metatranscriptomics project has explored how combinations of starter bacteria interact to influence a cheddar's buttery, nutty, fruity and creamy flavours.



Also in this issue

chemaust.raci.org.au

The promises and perils of performing chemistry with AI

The pace at which artificial intelligence is becoming embedded in our lives has been astonishing. Chemistry is no different.

This issue of *Chemistry in Australia* features a report describing how a lab used AI to design and carry out a chemistry experiment in just minutes (p. 20). It's a fascinating example of how AI can accelerate "the pace and number of scientific discoveries, as well as improve the replicability and reliability of experimental results". This is one of the "good" AI stories.

Balanced against this are the "bad" AI narratives, and some of these are already being witnessed. For instance, last November a team from the Lawrence Berkeley National Laboratory in the US reported the discovery of 41 novel inorganic compounds in just 17 days (doi.org/10.1038/s41586-023-06734-w). However, by early January an analysis published as a preprint on *ChemRxiv* (doi.org/10.26434/chemrxiv-2024-5p9j4) pointed out "four common shortfalls in the analysis. These errors unfortunately lead to the conclusion that no new materials have been discovered in that work ... The predicted compounds investigated herein have all their elemental components located on distinct crystallographic positions, but in reality, elements can share crystallographic sites". As a result, "two-thirds of the claimed successful materials ... are likely to be known, compositionally disordered versions of the predicted, ordered compounds".

Co-author Professor Gerbrand Ceder defended the study on LinkedIn: "We have no doubt that a human can perform a higher-quality refinement on these samples", he wrote. "However, it was our objective to show what an autonomous laboratory can achieve."

The problem with this statement is the authority that a peer-reviewed paper in *Nature* provides this "experiment within an experiment". Ceder's group may have shown what AI can achieve, and also what it can't, but when we see chemistry claims published in *Nature* we expect something more reputable than the output of ChatGPT. Human intelligence must not be forfeited.

Elsewhere in the literature, AI is undermining the authority of scientific research through the proliferation of "paper mills", which generate fake research papers for people who want to boost the publication count on their CVs. According to *Nature*: "There are hundreds of thousands of bogus 'paper-mill' articles lurking in the literature" (doi.org/10.1038/d41586-023-03464-x).

Ironically, AI programs are being employed to detect fake papers, but they will always be playing catch-up. Meanwhile, the trustworthiness of science and the integrity and replicability of the research record diminishes.

I'd like to acknowledge the professionalism of previous Editor Sally Woollett and ongoing Production Editor Catherine Greenwood, and their encouragement for me to take on the editorship of *Chemistry in Australia*.

Guy Nolch (editor@raci.org.au) is Editor of *Chemistry in Australia*.

New Editor for *Chemistry in Australia*

Chemistry in Australia has a new Editor with the appointment of Guy Nolch.

Guy is an experienced scientific editor, having commenced his publishing career with peer-reviewed journals before being appointed as Editor of *Search*, the journal of the Australian and New Zealand Association for the Advancement of Science. Since then he has been the Editor and Publisher of the popular science magazine *Australasian Science* and the history journal *Agora*, edited school textbooks as well as journals for professional organisations, written articles and editorials for newspapers and magazines, founded and presented the science program *Einstein A Go-Go* on 3-RRR FM, and presented segments on Radio National's *Science Show* and *Ockham's Razor*. He also co-authored *Dangerous Australian animals* with toxicologist Professor Struan Sutherland.

Guy is no stranger to RACI, having worked on the production of *Chemistry in Australia* for two decades.

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Changing careers

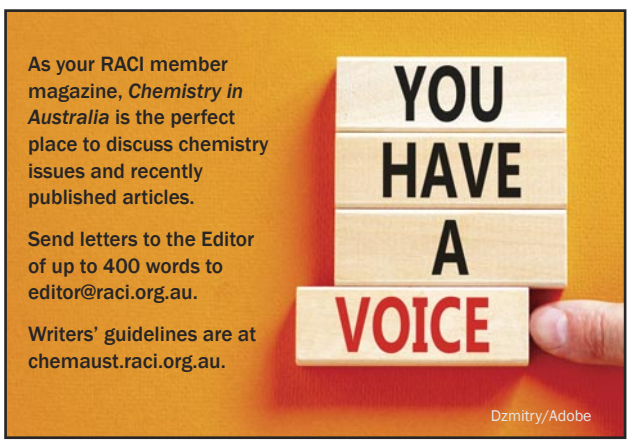
I was most interested in the piece "Hanging up the lab coat" by Barbara Cosson and Janine Pickering (December 2023 – February 2024, p. 40), in particular its advice on making a fundamental change in late career. After reading it, I recalled Dr Jane Burch née Ramsey (1926–2010), who was at the University of Leeds in my time there. I was only ever in her company once, and that was almost 50 years ago, but much more recently I have exchanged emails with her family.

Dr Burch's background was unusual. Her father was the scholar Frank Plumpton Ramsey (1903–30), who, in spite of his early death from a liver complaint, became "founder of whole areas of mathematics and economics besides major theories in philosophy" (Mellor D.H., "Ramsey, Frank Plumpton", *Oxford Dictionary of National Biography* 2005). Frank's brother was Arthur Michael Ramsey (1904–88), who was Archbishop of Canterbury, no less, from 1961 to 1974. Their father was the mathematician Arthur Stanley Ramsey (1867–1954), Fellow of Magdalene College, Cambridge. After Frank's death, his widow, Lettice Ramsey, went into business with Helen Muspratt as a photographer.

Jane Ramsey studied science at Newnham College, Cambridge and received a PhD in biochemistry in 1949. She married physicist Philip Burch, who moved from Cambridge to Leeds, where he ultimately became Professor of Medical Physics. They had three children. Jane was appointed to the Department of Biochemistry at Leeds on a part-time basis, and she continued at that until she retired in 1991, by which time Philip Burch had died. In 1989, Jane published a compilation of her husband's work.

The relevance of all this to Barbara and Janine's article in *Chemistry in Australia* is that after retirement Jane Burch worked with the Citizens Advice Bureau in Leeds. She did so until shortly before her death. So there is an example of a "transition as a mature-age professional". Jane would have brought into play as an officer of the Citizens Advice Bureau the gifts that had enabled her to distinguish herself much earlier in life. I cannot be sure, but I rather imagine that both colleagues and clients at the Citizens Advice Bureau would have been encouraged to address her simply as Jane.

Clifford Jones FRACI CChem



Anonymisation promises equity and diversity in Australian research

A multi-year study led by the office of Australia's Women in STEM Ambassador, Professor Lisa Harvey-Smith, has found that removing identifying names and other information on applications for access to research facilities in Australia significantly benefitted early-career researchers, offering them an increased chance of success, irrespective of gender.

"Our focus was on finding out how organisations could create an equitable research environment. Anonymisation proved to be a powerful tool", said Dr Isabelle Kingsley, lead researcher of the study (doi: 10.31219/osf.io/jyq2f).

The study found:

- before anonymisation, no gender gaps in application outcomes were observed
- the introduction of anonymisation maintained the existing gender equity landscape
- anonymisation enhanced success rates for early-career researchers, fostering diversity in the research pool
- anonymisation made a positive impact on the broader retention and advancement of researchers facing barriers in STEM research.

"Securing access to research facilities is as pivotal as winning grants. Anonymisation levels the playing field, making it less about prestige and more about merit", Kingsley said.

"This study goes beyond the usual assumptions about anonymisation in competitive grants, and highlights the real struggles of early-career researchers in academia", Harvey-Smith said. "Anonymising applications removes access to information that can lead to psychological biases, offering a fairer assessment for all applicants."

The study's impact extends beyond application outcomes, potentially creating a positive ripple effect in the STEM career pipeline. Removing personal information from applications can be a catalyst for removing systemic barriers to career advancement.

"Access to research facilities is just one piece of the puzzle in STEM inequity", Harvey-Smith said. "Anonymisation addresses a crucial aspect, fostering a more inclusive and diverse research landscape."

Australian Government's Women in STEM Ambassador

Help steer *Chemistry in Australia*

The *Chemistry in Australia* management committee is seeking new members with a range of backgrounds, expertise and interests. The committee meets four times per year via Zoom to discuss editorial, financial and other matters arising, and reports to the RACI Board.

If you'd like to join the committee, send details of your experience and interests to richard.thwaites@bigpond.com.

Polyethylene waste upcycled

An international team of experts undertaking fundamental research has developed a way of using polyethylene waste (PE) as a feedstock, and converted it into valuable chemicals through light-driven photocatalysis.

Professor Shizhang Qiao of the University of Adelaide's School of Chemical Engineering led the team, which published its findings in *Science Advances* (doi:10.1126/sciadv.adk2407).

"We have upcycled polyethylene plastic waste into ethylene and propionic acid with high selectivity using atomically dispersed metal catalysts", said Qiao.

"An oxidation-coupled room-temperature photocatalysis method was used to convert the waste into valuable products with high selectivity. Nearly 99% of the liquid product is propionic acid, alleviating the problems associated with complex products that then require separation.

"Renewable solar energy was used rather than industrial processes that consume fossil fuel and emit greenhouse gases. This waste-to-value strategy is primarily implemented with four components, including plastic waste, water, sunlight and non-toxic photocatalysts that harness solar energy and boost the reaction. A typical photocatalyst is titanium dioxide with isolated palladium atoms on its surface."

Most of the plastics used today end up being discarded and accumulated in landfills. PE is the most widely used plastic in the world. Daily food packaging, shopping bags and reagent bottles are all made from PE. It is also the largest proportion of all plastic waste and primarily ends up in landfill, posing a threat to global environment and ecology.

"Plastic waste is an untapped resource that can be recycled and processed into new plastics and other commercial products", said Qiao."Catalytic recycling of PE waste is still in early development and is practically challenging because of chemical inertness of polymers and side reactions arising from structural complexities of reactant molecules."

Current chemical recycling for PE waste is operated at high temperatures (>400°C) that yield complex product compositions.

Ethylene is an important chemical feedstock that can be further processed into a variety of industrial and daily products, while propionic acid is also in high demand owing to its antiseptic and antibacterial properties.

The team's work aims to address contemporary environmental and energy challenges, contributing to a circular economy. It will be of use in further scientific research, waste management and chemical manufacturing.

"Our fundamental research provides a green and sustainable solution to simultaneously reduce plastic pollution and produce valuable chemicals from waste for a circular economy", said Qiao.

"It will inspire the rational design of high-performance photocatalysts for solar energy utilisation and benefit the development of solar-driven waste upcycling technology."

University of Adelaide

Chemists identify three recreational drugs never before seen in Australia

Three new recreational drugs that have never been reported in Australia before have been identified by chemists at Australia's only fixed-site drug checking service, CanTEST.

According to scientists and clinicians from the Australian National University (ANU), the drugs could have effects similar to other stimulant-like substances such as MDMA (also known as ecstasy) and ketamine, a drug used as an anaesthetic for medical purposes. It's not yet known how dangerous these substances are or what short- and long-term health impacts they have on the user.

ANU Professor Malcolm McLeod FRACI CChem, who is also Chemistry Lead at CanTEST and Pill Testing Australia, said one substance submitted for testing, which the client believed to be a derivative of Ritalin, a stimulant used to treat ADHD, was actually a new variant of cathinone or 'bath salts' – a dangerous family of chemicals that in some cases have proven lethal. "Although there are a range of cathinone variants circulating in the community, finding a new one is obviously of concern because we don't know how it will affect people or what the health consequences are," McLeod said.

"The second substance we analysed, which the client believed to be a ketamine-like substance, was in fact a new type of benzylpiperazine stimulant, often used as a substitute for MDMA. While derivatives of these stimulants first emerged in New Zealand in the early 2000s, we actually don't know a lot about them.

"As for the third one, the client reported some uncertainty about the identity of the substance. They thought it was a cathinone drug, a stimulant that can have similar effects to amphetamines, but wanted to have it tested to avoid any nasty surprises. We later identified the drug to be a new phenethylamine drug known as propylphenidine. Phenethylamines are a category of stimulant drugs that includes amphetamine, methamphetamine and MDMA."

The on-site analysis of all three substances at CanTEST ruled out the expected substances but proved inconclusive. Further laboratory testing at the ANU Research School of Chemistry helped scientists identify the true nature of the drugs.

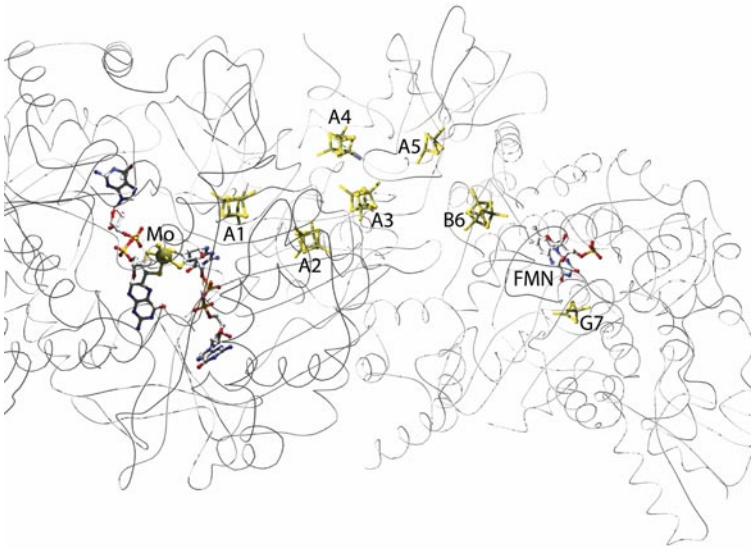
CanTEST has analysed more than 1700 samples since opening in July 2022. In late 2022, chemists made a potentially life-saving discovery after detecting a highly dangerous opioid in pills that were falsely sold as oxycodone, triggering a public health alert. An evaluation of the first six months of CanTEST found one-in-10 samples submitted for testing were discarded once the client learnt what was in them. It also found more than half of the drugs tested at the clinic were not what the user expected.

The researchers' work analysing the three new substances was published in *Drug Testing and Analysis* (doi:10.1002/dta.3637).

Australian National University, CanTEST Health and Drug Checking Service

It's complex

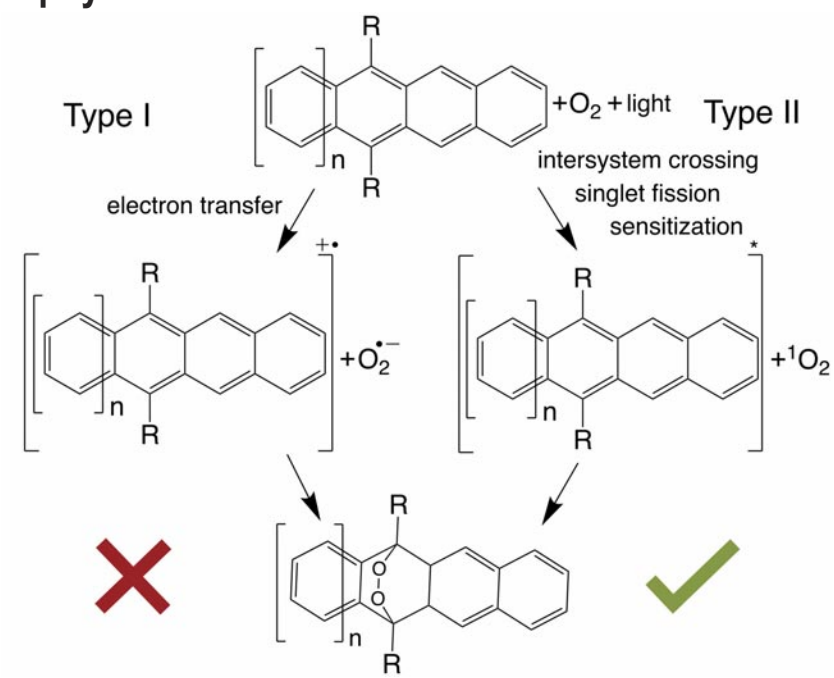
The pursuit of methods to capture and reduce CO_2 to formic acid continues to be a focus of many chemists, as is evident from browsing the contents of all major general chemistry journals. Nature has already found a solution to this challenge through the bacterial molybdenum-dependent enzyme formate dehydrogenase (FdsDABG). FdsDABG oxidises formate to CO_2 but, importantly, it can also reduce CO_2 to formate. Paul Bernhardt at the University of Queensland (UQ) has employed electrochemistry with FdsDABG to generate formate from CO_2 at its thermodynamic potential (–0.43 V vs the standard hydrogen electrode at pH 7). FdsDABG is an especially complex enzyme, bearing nine different redox cofactors: the molybdenum (Mo) active site, seven Fe/S clusters (A1–G7) and a flavin mononucleotide (FMN). Bernhardt's collaboration with electron paramagnetic resonance spectroscopist Jeff Harmer at the UQ Centre for Advanced Imaging and biochemist Russ Hille at the University of California, Riverside (US), successfully determined the redox potentials of eight of these nine centres through electron paramagnetic resonance redox titrations and optical spectroelectrochemistry (Harmer J.R., Hakopian S., Niks D., Hille R., Bernhardt P.V. *J. Am. Chem. Soc.* 2023, **145**, 25 850–63).



This is the first redox characterisation of a complex formate dehydrogenase and lays the foundation for future applications of this air-stable enzyme as a catalyst for CO_2 reduction.

Ultrafast and ultraslow spectroscopy clarify oxygen's role in polyacene photodegradation and photophysics

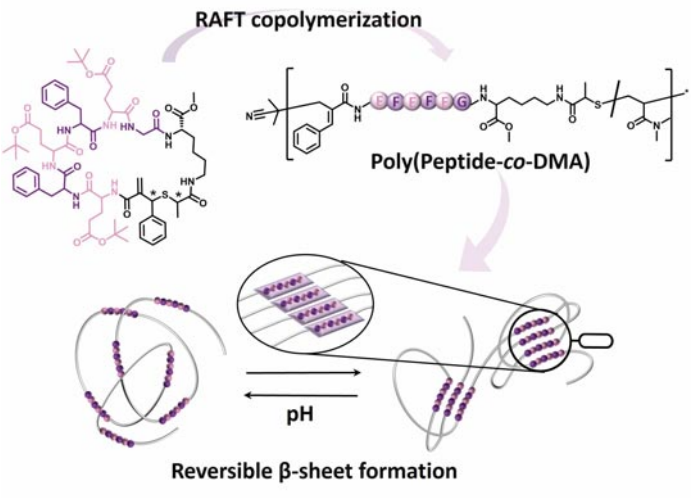
Polyacene chromophores and their derivatives are extensively studied as model systems for singlet fission and triplet fusion, which are photophysical processes with great potential to enhance photovoltaic efficiency, among other applications. But the propensity of these polyacenes to photodegrade in the presence of oxygen limits their use in real-world applications. Two main mechanisms for the reaction of polyacenes with oxygen have been proposed, each leading to different design rules to mitigate the process, but the relative importance of each has been unclear until now. Researchers at the University of Adelaide have used spectroscopy to model the photophysics and photodegradation of polyacenes on multiple time scales, which allowed them to determine the predominant mechanism of photodegradation and to establish the general effects of oxygen on polyacene photophysics (Stuart A.N., Kee T.W., Huang D.M. *J. Am. Chem. Soc.* 2024, **146**, 2174–86). They demonstrated



that oxygen reacts selectively with different spin-excited states, and affects the photophysics of polyacenes in multiple ways beyond simple triplet quenching. These findings provide important context for future studies of the photophysics of these systems, and will aid the design of more photostable materials for singlet-fission or triplet-fusion applications.

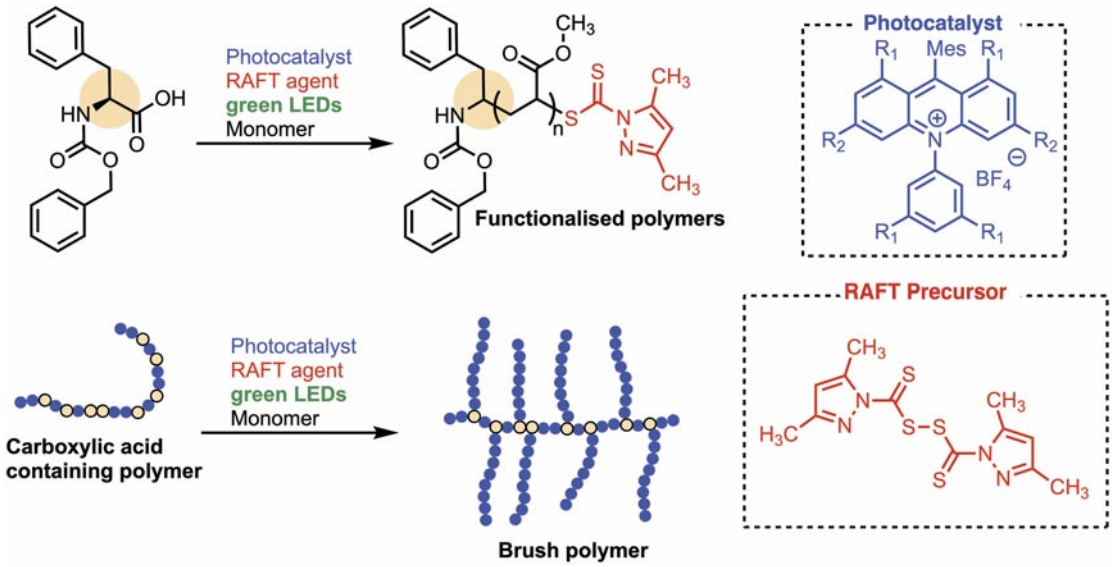
Using peptide self-assembly to control synthetic polymer folding

The function of a protein is enabled by its precise 3D structure, which is the result of folding of a sequence-defined polypeptide chain. This hierarchical process starts with the formation of secondary structures (e.g. α-helices and β-sheets) through hydrogen bonding between the backbone amides. The ensemble of secondary structures in turn shapes the overall tertiary structure. A plethora of strategies has been developed to mimic and control the folding process of synthetic polymers. However, nature's architectural sophistication remains unmatched, due to the challenging synthesis of long, sequence-defined polymers with functional backbones. Circumventing the need for entirely sequence-defined polymers, work from QUT's Soft Matter Materials Laboratory led by Hendrik Frisch and PhD student Federica Sbordone reports the use of short peptide sequences that are embedded into the main chain of vinylic polymers to determine the function of the synthetic polymer (Sbordone F., Micallef A., Frisch H. *Angew. Chem. Int. Ed.* 2024, doi.org/10.1002/anie.202319839). In water, changes in pH lead to the deprotonation/protonation of weakly acidic amino acids, thereby either inducing or disrupting intramacromolecular β-sheet-encoded hydrogen bonding. The pH at which these distinct polymer conformations appear is programmed into the polymer chain by the choice of amino acid sequence and can be synthetically adjusted.

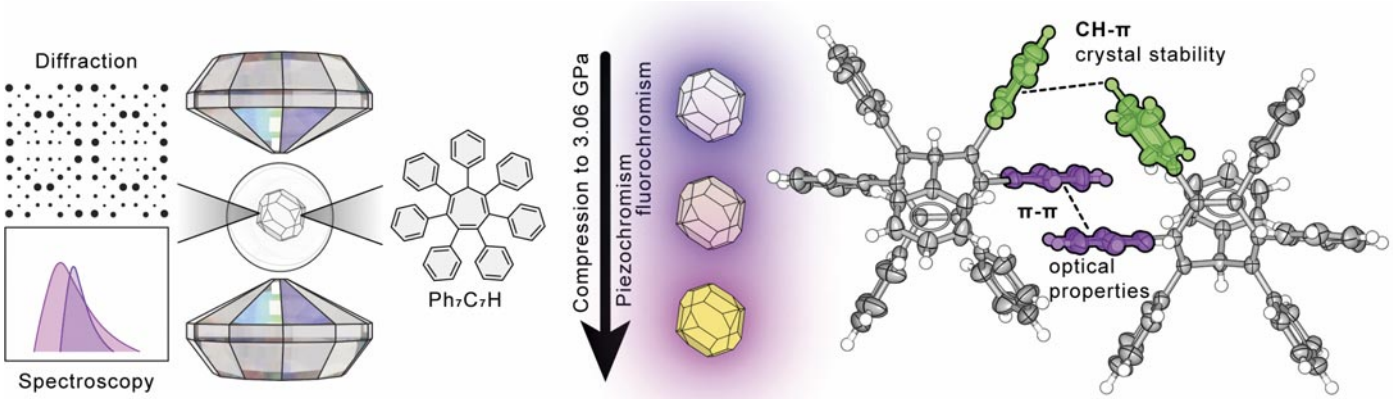


Single-step RAFT graft

Many advanced applications of polymer science require polymers to be covalently attached (or grafted) to other molecules, materials or surfaces. This is often a multistep process, as the target for grafting must first be modified to include particular functional groups that can then initiate the polymerisation. In a new approach from the Hooper research group at Monash University, reversible addition–fragmentation chain-transfer (RAFT) polymers were grafted in a single step from small molecules and polymers through a photochemical radical decarboxylation reaction (Ayurini M., Haridas D., Mendoza D.J., Garnier G., Hooper J.F. *Angew. Chem. Int. Ed.* 2024, **63**, e202317071). The method uses an organic photocatalyst and green light to generate radicals via the decarboxylation of carboxylic acid functional groups on the target molecules. This radical is then intercepted by a RAFT precursor agent, which allows for controlled radical polymerisation driven by light. Given the ubiquity of carboxylic acids in bioactive small molecules, biopolymers and synthetic polymers, this approach offers the ability to synthesise a host of functionalised polymer materials in a simple and efficient manner.

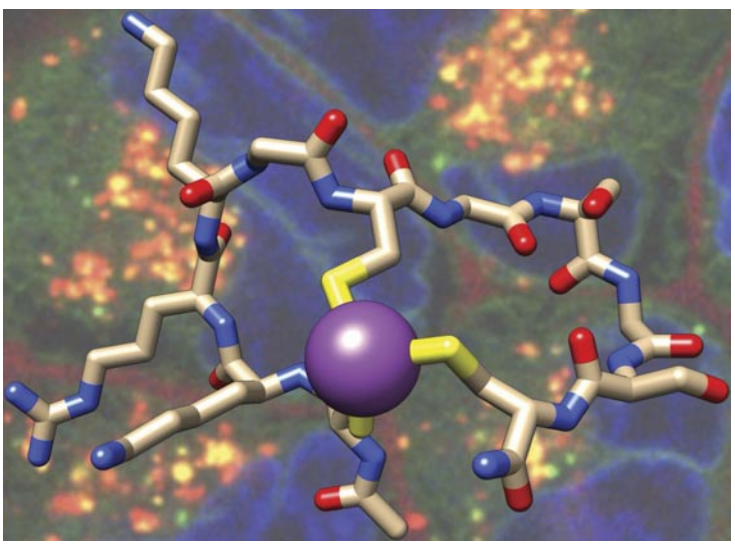


Unpacking structure–fluorescence relationships in organic crystals



Fluorescent crystals are used in components of numerous optoelectronic technologies, from OLED displays to photovoltaic devices. Organic fluorescent crystals typically form from molecules with a cyclic core surrounded by aromatic substituents that form rotor-like geometries, which prevents non-radiative decay in the solid state and leads to fluorescence. The geometry of non-covalent interactions between aromatic substituents is known to affect optical properties of the crystal, but more developed structure–optics relationships are required to better understand these compounds. Researchers from the University of Western Australia, Durham University (UK) and the University of Edinburgh (UK) have drawn explicit connections between the structural and optical properties of a classical fluorescent organic crystal, *sym*-heptaphenylcyclopentadiene (Ph_7C_7H), by combining high-pressure X-ray crystallography, high-pressure fluorescence and absorption spectroscopies, and computation (Sussardi A.N., Turner G.F., Richardson J.G., Spackman M.A., Turley A.T., McGonigal P.R., Jones A.C., Moggach S.A. *J. Am. Chem. Soc.* 2023, **145**, 19 780–9). The fluorescence wavelength and colour of the crystal can be tuned by compression of the π–π interactions, but the stability of the crystal is dictated by the CH–π interactions, which are often overlooked. Such interactions are pervasive in fluorescent organic crystals, so this structure–fluorescence dependence is expected to be applicable to similar systems.

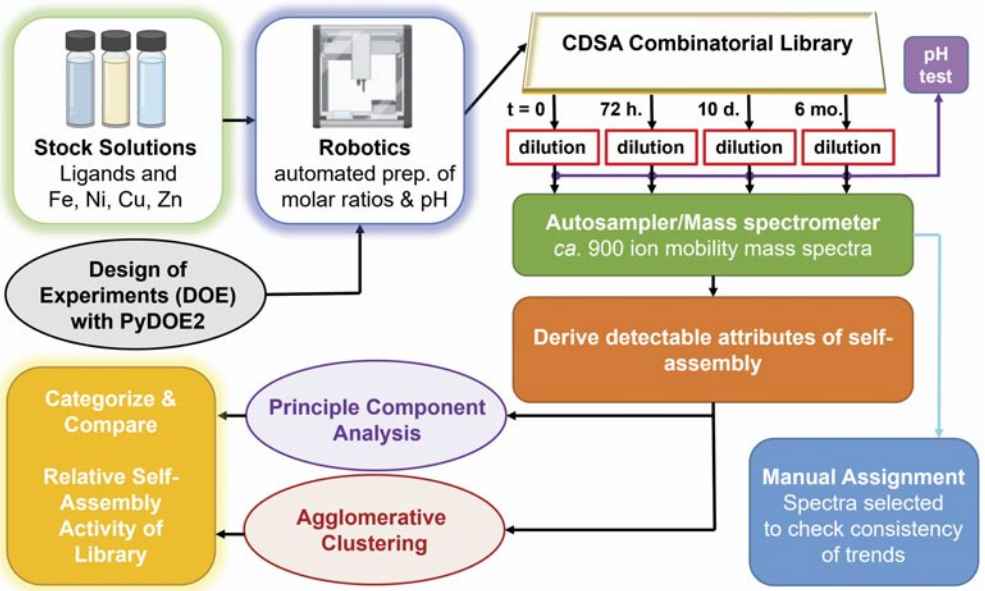
Breaking barriers in drug delivery



Cell-penetrating peptides play a crucial role in transporting cargo, including drugs, across human cell membranes. Enhancing the effectiveness of this process involves forcing the peptide into a more constrained shape, enabling sufficient cell penetration at lower concentrations. A straightforward method for constraining peptides into a bicyclic shape involves Bi^{III} binding to three cysteine residues, a technique pioneered by the Nitsche group at the Australian National University (ANU). In a recent development, an international team comprising scientists from the ANU, Free University of Berlin (Germany), University of Sydney and Heidelberg University (Germany) has applied this strategy to explore peptide–bismuth bicycles as a new class of cell-penetrating peptides (Voss S., Adair L.D., Achazi K., Kim H., Bergemann S., Bartenschlager R., New E.J., Rademann J., Nitsche C. *Angew. Chem. Int. Ed.* 2024, **63**, e202318615). These peptides outperform conventional cell-penetrating peptides such as TAT or octaarginine and require as little as three positive charges to traverse cell membranes at nanomolar concentrations. While these peptides can be linked to fluorescent dyes for monitoring cellular uptake through microscopy, uptake can alternatively be tracked by mass spectrometry of bismuth, providing a novel method to study cell-penetrating peptides without the need for fluorescent labels.

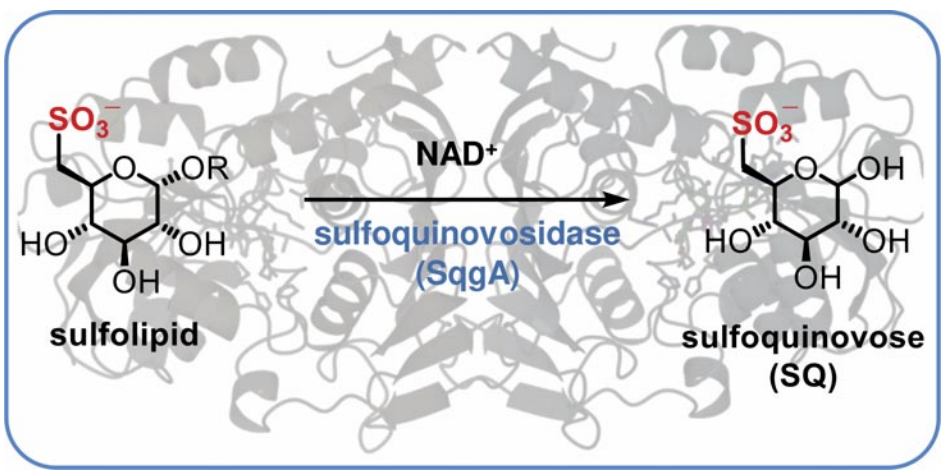
Embracing design complexity by automatically processing self-assembly

Metallo-supramolecular self-assembly presents an opportunity for fabricating materials of economic significance. While the diversity of accessible supramolecules is alluring, practical implementation can be hampered by limitations in characterising complex mixtures, as the individual components and combinations thereof are inherently challenging to resolve. Researchers led by Nicole Rijs at UNSW Sydney have recently used a large robotically prepared combinatorial library of transition metals and β-diketonate ligands at different molar ratios and pH values to directly analyse self-assembly activity via critical characteristics (Lloyd Williams O.H., Rusli O., Ezzedinloo L., Dodgen T.M., Clegg J.K., Rijs N.J. *Angew. Chem. Int. Ed.* 2024, **63**, e202313892). The analysis was carried out using electrospray ionisation ion mobility mass spectrometry. Using ion mobility allows structural characteristics of isomers to be part of the analyses, unlike mass spectrometry alone, which is typically limited to stoichiometry and connectivity via fragmentation. The data set was parsed for self-assembling activity without first attempting to structurally assign individual species. The activity was readily categorised without manual data handling, allowing for efficient screening. The complex behaviour was reduced to simpler qualities, which could be automatically processed. This is a step towards filling the recently highlighted dearth of scalable analytical methods needed for materials discovery via high-throughput methods and AI.

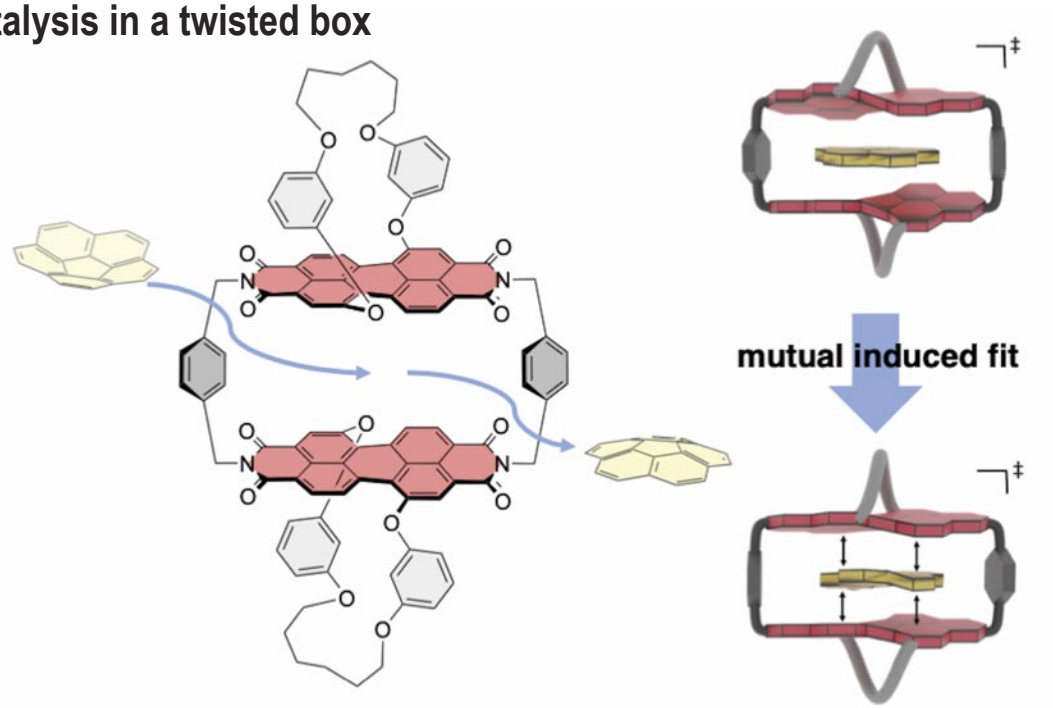


Enzyme alchemy in the sulfur cycle

Sulfolipids, produced by photosynthetic organisms on a massive scale of 10 billion tonnes annually, are broken down for carbon and sulfur recycling. This process involves sulfoquinovosidases (SQases), which are glycoside hydrolases that hydrolyse sulfolipids to release sulfoquinovose (SQ). Researchers at the University of Melbourne isolated bacteria in Australian soils with an SQ degradation pathway but lacking an SQase (*Arch. Microbiol.* 2022, **204**, 193). This conundrum was resolved by a team from the University of Melbourne, the University of York (UK) and the Walter and Eliza Hall Medical Institute, which discovered a novel family of SQases (Kaur A., Pickles I.B., Sharma M., Madeido Soler N., Scott N.E., Pidot S.J., Goddard-Borger E.D., Davies G.J., Williams S.J. *J. Am. Chem. Soc.* 2023, **145**, 28 216–23). Mechanistic and structural studies revealed that these enzymes use NAD^+ to transiently oxidise SQ glycosides and facilitate hydrolysis through an elimination/addition process. These novel SQases are widespread in marine bacteria, suggesting a significant role in marine sulfur cycling.



Mutual induced fit catalysis in a twisted box



Mutual induced fit, whereby both the host and substrate geometrically adapt to optimise binding, is a well-known phenomenon in enzyme catalysis and biomolecular recognition but is less common in synthetic systems. A collaboration between experimental chemists from Universität Würzburg (Germany) and computational chemists from Flinders University and the University of New England has explored how mutual induced fit catalysis allows a chirally twisted cyclophane to accelerate the bowl-to-bowl inversion of the well-known fullerene fragment corannulene (Weh M., Kroeger A.A., Anhalt O., Karton A., Würthner F. *Chem. Sci.* 2024, **15**, 609–17). Computational models of the catalytic system supported by crystallographic studies using a transition structure analogue revealed that complexation of corannulene with the twisted cyclophane leads to an unusual distortion of its otherwise planar bowl-inversion transition structure along with partial planarisation of the cyclophane walls. This maximises the stabilising π–π stacking interactions between the host and guest, leading to the experimentally observed and computationally predicted reduction in the bowl-to-bowl inversion barrier.

Compiled by **David Huang** MRACI CChem (david.huang@adelaide.edu.au). This section showcases the very best research carried out primarily in Australia. RACI members whose recent work has been published in high-impact journals (e.g. *Nature, J. Am. Chem. Soc., Angew. Chem. Int. Ed., Chem. Sci.*) are encouraged to contribute general summaries, of no more than 200 words, and an image to David.

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How microbial interactions shape the flavour of cheese

BY **CHRATS MELKONIAN** AND **AHMAD A. ZEIDAN**

A metatranscriptomics project has explored how combinations of starter bacteria interact to influence a cheddar's buttery, nutty, fruity and creamy flavours.

Microbes play a pivotal role in the food industry. Their metabolic activity through fermentation underlies the production of a large part of our diet, from fermented beverages like wine, beer and kombucha to fermented dairy products such as kefir, yoghurt and cheese.

Cheese fermentation involves complex interactions among several microbial species. Alongside traditional and modern cheesemaking processes, the wide diversity of microbes used in cheese fermentation results in a rich global cheese platter, placing cheese among the top foods in terms of its significant cultural dimensions and socioeconomic relevance.

While much is known about the effect of individual microbes on cheesemaking, less is understood about their interactions within the context of the microbial community. To shed light on the molecular mechanisms underlying such complex interactions, a project named FoodTranscriptomics was initiated by Chr. Hansen, a Denmark-based global bioscience company. The multidisciplinary expertise among the research partners spanned microbiology, food science, biochemistry, bioinformatics and mathematical modelling.

A multi-year research project

In cheesemaking, the initial step of milk fermentation is fairly well studied. This project instead focused on the long period of cheese ripening, which has a significant effect on the final flavour of the cheese. The main work started with a year-long experiment

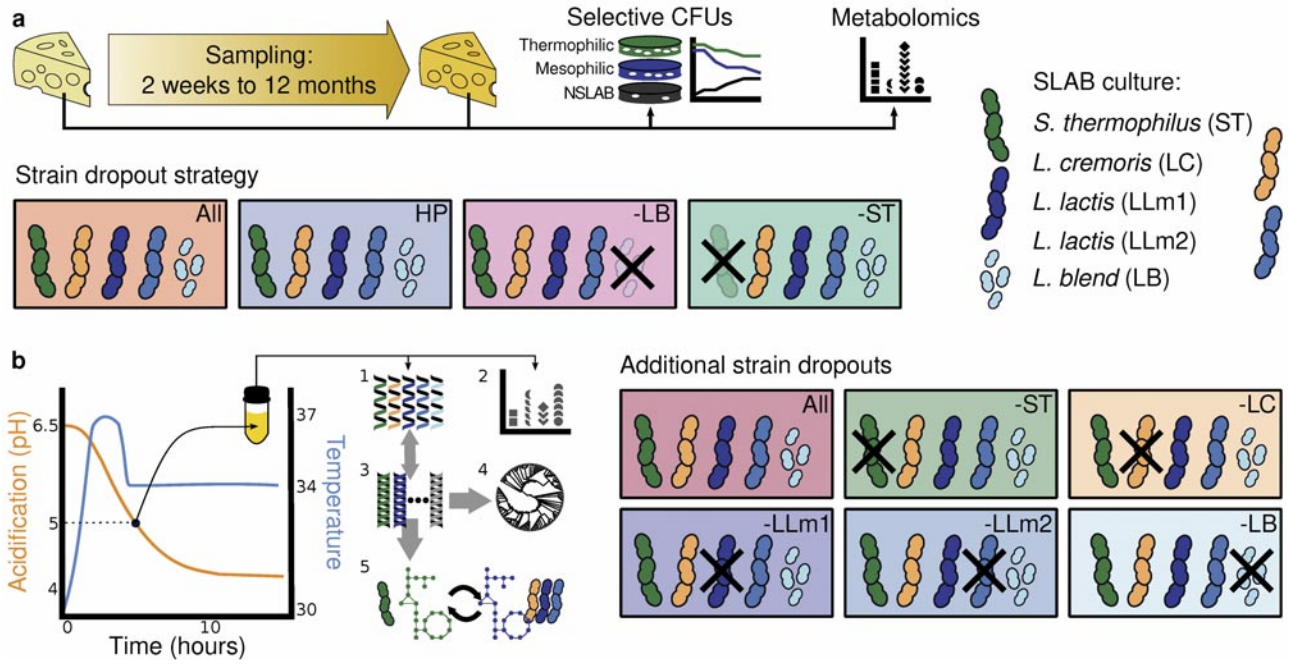

Figure 1 (a) The year-long cheddar-making experiment. **(b)** The controlled milk experiment in the laboratory.

involving the production of cheddar cheese while varying the key members of a multi-strain commercial cheese starter culture comprising:

- *Streptococcus thermophilus*
- two major *Lactococcus lactis* strains
- one major *L. cremoris* strain
- a mixture of 21 *L. cremoris* and *L. lactis* strains (Fig. 1a).

The microbial dynamics were then investigated by selective plating and counting of bacterial colonies after 2 weeks and then after 3, 6, 9 and 12 months.

In addition, an array of targeted biochemical measurements were employed at the same time intervals to understand the chemical changes during cheese ripening. Advanced technologies, such as liquid and gas chromatography combined with mass spectrometry, were used to measure carbohydrates, organic acids, peptides, amino acids and volatile compounds (Fig. 1a).

To gain a deeper understanding of the molecular mechanisms underlying the microbial interactions in cheese fermentation, we devised a second experiment involving controlled milk fermentations where additional strains were removed from the starter culture and various samples were harvested at pH 5 (Fig. 1b). Here we took an integrative systems biology approach that combined genomics, genome-scale metabolic modelling, meta-transcriptomics and exo-metabolomics.

Metabolic interactions between microbes shape the biochemical profile of cheese

The results of the year-long cheesemaking experiment indicated that *S. thermophilus* benefits the growth of the lactococci community. This was evidenced by the significantly fast decline in the *Lactococcus* population when *S. thermophilus* was removed from the culture. In addition, the metabolic activity of *S. thermophilus* had a significant impact on the chemical profile of the cheese from the early stages to the final stage of the ripening process. This was especially pronounced in the final peptide compositions we observed.

Digging deeper to identify the underlying mechanisms revealed that *S. thermophilus*, through its proteolytic enzymes, provides peptides and amino acids as nitrogen sources to *Lactococcus*. Metabolic modelling and metatranscriptomics analysis revealed that *S. thermophilus* is likely to excrete branched-chain amino acids as a result of its metabolic activity. When *S. thermophilus* was removed from the starter culture, the *Lactococcus* community exhibited a significant upregulation in nucleotide biosynthesis through glutamine, purine and pyrimidine biosynthesis pathways, which are essential for cell maintenance.

While our results suggested a collaborative interaction between the microbes, we also observed competition between *L. lactis* and *L. cremoris* for available nutrients in the milk, such as citrate. C4 aroma compounds, such as diacetyl and acetoin, are derivatives of citrate metabolism and lead to a buttery flavour. By investigating the transcriptome profile of the microbial community, we found that all *Lactococcus* strains are likely to take up citrate.

While *L. lactis* appears to be primarily directed towards the production of diacetyl and acetoin,

A cheese vat during the washing of the curd. © Chr. Hansen A/S

Our results … provide targets towards the rational design and assembly of microbial communities with the aim of fine-tuning the flavour of cheese.

affecting the cheese's buttery traits, *L. cremoris* exhibits a transcriptionally active pathway that produces α-ketoglutarate. *L. cremoris* also possesses active genes associated with aconitate hydratase and isocitrate dehydrogenase. These are involved in intracellular metabolic conversions and are not as relevant for flavour.

When *L. cremoris* was removed, we detected four flavour compounds. These included 2,3-pentanedione (which gives the flavour of nuts, cream and butter), and heptanal and hexanal (which taste fruity and fatty). On the contrary, the presence of *L. cremoris* led to higher amounts of 2-methyl-3-thiolanone (which adds a meaty flavour) as well as the esters ethyl acetate and ethyl hexanoate (which add a fruity flavour).

Overall, these findings led us to hypothesise that competition between bacterial species induces changes in crucial flavour compounds. These include diacetyl, acetoin and other compounds with unknown biosynthetic reactions responsible for the production of 2,3-pentanedione, esters and more. These compounds are typically associated with fruity, creamy, buttery and nutty flavours.

Our results show how strain-specific metabolic interactions between microbes shape the biochemical profile of cheese, and provide targets towards the rational design and assembly of microbial communities with the aim of fine-tuning the flavour of cheese. More broadly, our study provides a blueprint for uncovering in situ interactions in complex food microbial ecosystems.

The future awaits

Since an actual cheddar cheesemaking process was conducted, our findings are directly applicable to commercial cheese production processes. One of the key findings is that realising the desired flavour of a cheese depends not only on individual microbial traits but also on various interactions among microbes, even at a strain level. Our findings thus open the door to investigate microbial interactions in a wide range of cheeses and other types of fermented foods, as the microbes used here – *S. thermophilus*, *L. lactis* and *L. cremoris* – are heavily used in the fermented food industry.

The results resonate outside the dairy industry. An example is the growing area of plant-based food fermentation, where the removal of off-flavours and toxic compounds is essential for a pleasant and safe final product.

We have also shown that varying the conditions can switch collaborative microbial interactions to competitive interactions, and vice versa. This has also been observed by our project partners in kefir fermentation (doi.org/10.1038/s41564-020-00816-5).

Therefore, we believe that the nature of microbial interactions in a community should always be investigated in the context of the environmental conditions applicable to the community. The ultimate objective would be to rationally design microbial communities for food fermentations based both on individual traits and the potential interactions of microbes to achieve the desired food characteristics. To augment this mechanistic approach, data-driven mathematical models using AI can be of great value in accounting for unknown mechanisms, and thus accelerate the development of "designer" microbial cultures for food fermentations.

Beyond the realm of cheese, the FoodTranscriptomics project also explored the impact of microbial biochemical activity on reducing the alcohol level in wine. That research has been published in *Food Microbiology* (doi.org/10.1016/j.fm.2022.104167).

Chrats Melkonian is a postdoctoral computational microbial ecologist at Utrecht University/Wageningen University & Research, The Netherlands, and was first author of the research article. **Ahmad A. Zeidan** was the principal investigator of the cheese study in the FoodTranscriptomics project, and is the R&D Senior Director of Digital Innovation at Chr. Hansen A/S, Denmark.

The FoodTranscriptomics project was funded by Innovation Fund Denmark and involved a consortium of industrial and academic partners, including Chr. Hansen A/S, the European Molecular Biology Laboratory, Vrije Universiteit Amsterdam, the Technical University of Denmark and the University of Copenhagen. At a later stage, Francisco Zorrilla, supervised by Kiran R. Patil, from the University of Cambridge also contributed to the work, which was published in *Nature Communications* (doi.org/10.1038/s41467-023-41059-2).

On 29 January 2024, Chr. Hansen merged with Novozymes under the combined name of Novonesis.

Some of the flags representing collaborating nations at the Amundsen-Scott South Pole Station. Despite individual national interests and international challenges, collaboration has kept the Antarctic free from military conflict and nuclear proliferation.

National Science Foundation/Wikimedia Commons/Public Domain

International science collaborations in a contested world

BY **CHENNUPATI JAGADISH**

The *Defence Trade Controls Amendment Bill 2023* limits international scientific collaboration for security reasons, but its implications for research are much broader.

The global science system is at its most valuable, and its most vulnerable. There are local challenges that each country's scientists will need to solve, but the global challenges are different: bigger, harder and more complex, and political. They require global solutions, and that will require researchers and people to work together.

We face challenges from technologies born of science that were recently the stuff of dystopian Hollywood imagination – artificial intelligence, advanced robotics and quantum. And while they too demand collaborative science to deliver answers to government and society, they have fast become matters more characterised by strategic national competition than collaboration. But collaboration is a matter of strategic national interest, for everybody.

We in Australia can't do without international collaboration either. Our size and location make that obvious. We have to be willing and able to contribute to the knowledge bank that will help solve the challenges, and we need our scientists to be there when the big decisions are made that affect us and that affect the living systems in all other countries. We share one planet; we have nowhere else to go.

How do we in Australia navigate the next few months and years? How do we facilitate strategic collaboration?

The answers may well be among the most significant decisions we make as a nation. They will dictate our contribution to meeting global challenges. They will determine whether we develop the sovereign capabilities needed to secure our nation and globe. They will determine whether science is:

- adequately equipped to serve the national interest
- open enough to develop the technologies we need
- open enough to access the 96% of knowledge we don't generate
- protected enough to ensure our knowledge and capabilities do not fall into foul hands.

It's a conundrum of global proportions, and my own field of scientific endeavour illustrates why. My work in nanotechnology and semiconductors – an area of strategic competition between nations – is fuelled by my research group, which is entirely made up of international students. My work is also made possible because of some 30 collaborations I maintain across the world, spanning countries including the UK, the US, India, China, Germany, France, Sweden, Finland, Norway, Italy, the Netherlands, Japan, South Korea, Russia, Lithuania, Poland, Brazil, South Africa ... and the list goes on.

My work is fundamental discovery research, designed to better understand our world at a nanoscale. To put this into perspective, I can place 20 lasers in one strand of your hair. Why would I want to do that? Because at the nanoscale, I can create technology to better diagnose disease and understand and treat Alzheimer's disease in the longer term. I can create technology that more efficiently runs solar cells and generates hydrogen as a sustainable fuel source needed to decarbonise our industries and economy.

The trouble is, my research is also listed on the Defence and Strategic Goods List. Category 6, specifically 6A004, 6A005, 6A007 … the number soup goes on. And this means, placed in the wrong hands, my research could be used for less than desirable purposes.

On 7 November 2023, a new piece of legislation was released designed to strengthen Australia's defence export control framework so it keeps pace with the emerging challenges in Australia's security environment. The Exposure Draft of the *Defence Trade Controls Amendment Bill 2023* proposes to strengthen our defence export control framework by, among other things, creating three new criminal offences in the *Defence Trade Controls Act 2012*.

It says I can collaborate freely with the US and the UK – which certainly has its benefits – but I would require an approved permit prior to collaborate with other foreign nationals. Without it, my collaborations would see me jailed. So, it expands Australia's backyard to include the US and the UK, but it raises the fence.

For my research group, which consists entirely of PhD students, postdocs, technicians and senior researchers from countries other than the US and the UK, we will need permits for all that we do. And members of my group will need to operate in a closed environment to not unintentionally share knowledge that may have a dual use.

Discussion at international conferences, where unpublished knowledge is shared freely to solve research problems and enable collaboration, seems unlikely if this bill becomes law. Some of this may still be technically legal under this new legislation, but how will I know which session of these conferences I will be able to present at, ask questions or engage in discussions with or without a permit? My ability to attract the best

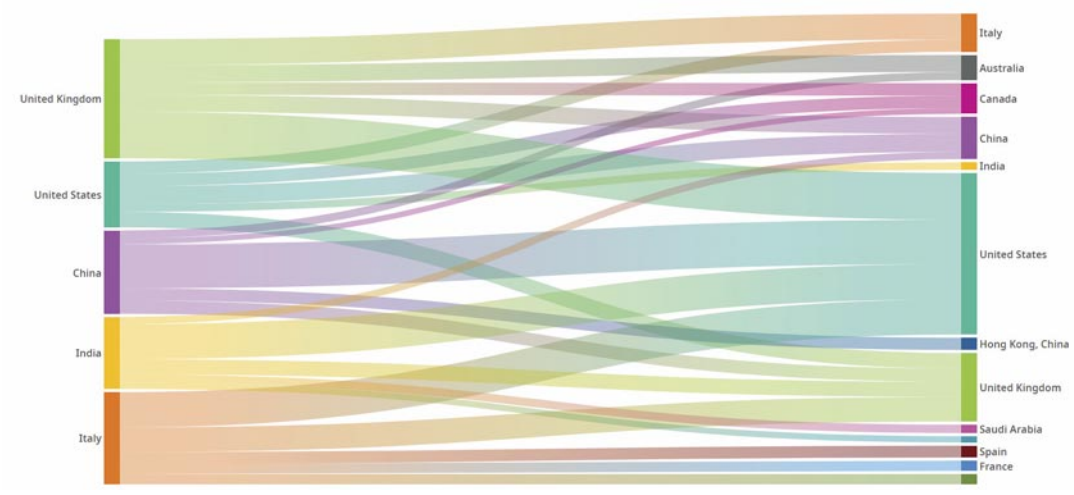

Fig. 1. International scientific collaboration on COVID-19 research, 1 January to 30 November 2020, 74 115 documents: flow of research collaboration. Left: Top 5 countries in terms of COVID-19 research publications. Right: Top countries and economies with whom each collaborated the most. OECD (2021) OECD Science, Technology and Innovation Outlook 2021

and brightest in the world, wherever they are, will diminish.

It's timely to ask what Australia is really seeking to secure if we are restricting the development of technologies that are critical for our country. In my experience and the experience of researchers worldwide, the best research is global. But, to comply with the new laws I will have to lock down my communications and restrict my collaborations.

It feels like I am being asked to create something akin to the US' federally funded research and development centres or university-affiliated research centres, minus the funding. These centres are not-for-profits that are established and funded to meet long-term engineering, research, development and analytical needs, like the Lincoln Lab at MIT. They are a mechanism used in the US to control risk but not limit collaboration for critical innovation.

If such structural change in the research architecture and system is required to address national security concerns, the Australian Government will need to consider the resource implications of implementing such changes:

- resources to establish secure research facilities
- resources to educate and train the workforce on the changing Defence and Strategic Goods List
- resources to foster a more security-aware culture across the research sector
- resources to facilitate compliance.

They will also need to accept the limitations of compliance. Students live in shared houses and university colleges; they go to cafes and to the student union. They don't only talk about the weather or the latest episode of their favourite show on Netflix. It's natural to share what they do – perhaps vent a frustration, seek reassurance about a doubt or celebrate a success.

It's timely to ask what Australia is really seeking to secure if we are restricting the development of technologies that are critical for our country.

We all do it because we are human. It ought not to be a jailable offence.

So, there is a lot at stake as we revise the architecture of our research system to respond to security threats. I am the first to agree that we need to do something to the changing geopolitical environment we need to operate in. But we ought not to throw the baby out with the bathwater. Australia is the product of the freedom of movement of scientists and our ability to collaborate and welcome talent to our shores.

Today, we have a National Reconstruction Fund, with a stated ambition to diversify and transform Australia's industry and economy. We are still 93rd in the world in terms of our economic complexity. In other words, we have a vulnerable economy that is underpinned by too few exports and industries, key among them unprocessed natural resources. So, more than ever, we need to diversify our industrial base and build onshore capabilities.

With these imperatives in mind, it is not a time to impede collaboration. Why? There is perhaps no better recent example of the benefit of international science collaboration than the development of COVID-19 vaccines. While the science behind mRNA was decades in the making, getting a vaccine to market in less than 12 months was a stunning achievement.

Take a look at Figure 1: on the left are the five countries that led in COVID-19 research efforts, and on the right are the countries they collaborated with the most. Australia is there on the right, having the most research publications with the UK and China.

Consider global efforts to develop large-scale infrastructure beyond the capacity of any one country, like the Square Kilometre Array (SKA). The SKA Observatory is one global observatory over two sites in South Africa and Australia, with associated data-processing facilities. It is achieved through a collaboration of member states and institutions, including Australia, China, Italy, the Netherlands,

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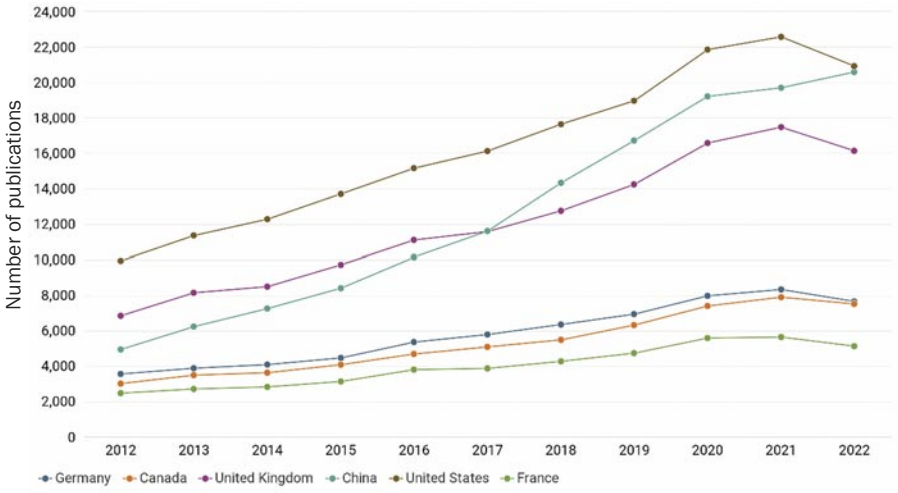


Fig. 2. Australia's international collaboration publications, Web of Science.
Chart: Australian Academy of Science. Source: Clarivate InCites

Portugal, South Africa, Spain, Switzerland and the UK. They collectively provide resources and knowledge, and industrial, technical scientific and policy experience, to realise the SKA.

Chinese industry and scientists have contributed to engineering design and development work. Their know-how and technology are built into this global infrastructure. We have been able to provide safeguards without erecting high fences.

Australian businesses are benefitting from the economic opportunities of being a host nation. And history has shown us that when we better understand the universe and its origins, it leads to unforeseen technological developments like wi-fi. Understanding our universe deepens our understanding of the fragility of Earth's ecosystems and helps us respond to variations to it. It enables our communications. The list goes on.

Could we achieve any of our innovations and competitive edge without collaboration? No. Let's be clear: the last major Australian invention that did not involve international input was the stump-jump plough. That was 1876. When we collaborate, we are stronger.

Let's look at Australian research trends over time. Australia is a relatively small market – 0.3% of the world's population – with low investment in R&D, by international standards, at 1.68% of our GDP. This has been falling for several years and is now well below the OECD average. Australia and Oceania together account for only 1.1% of the world's investment in research and innovation, a level that is dwarfed by the world's

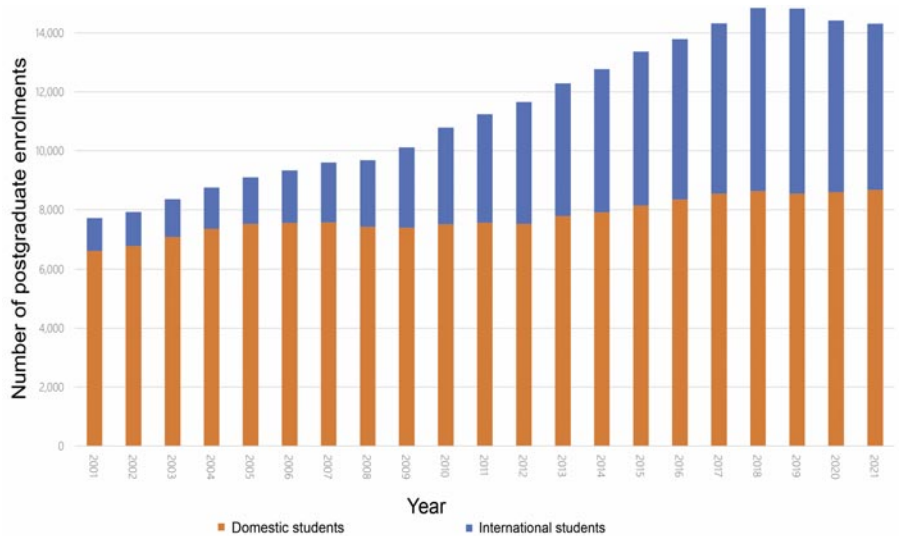


Fig. 3. Natural and physical science postgraduate research student enrolments.
Chart: Australian Academy of Science. Source: Department of Education, Australian Bureau of Statistics

Overall, international students represent 36% of Australia's postgraduate research students, who make up nearly a quarter of our research workforce ...

A composite image combining real images with artist's impressions of the three Square Kilometre Array Observatory sites: the headquarters in the UK, the SKA-Mid telescope in South Africa and the SKA-Low telescope in Australia. SKAO/CC-BY-3.0

science superpowers – the US (29%), China (37%) and Europe (22%).

We are a middle-power science nation. Despite this, we are prolific collaborators with significant influence in global science for our size. Looking at our share of global science, we contribute 3.5% of the world's research and 7% of the world's most highly cited research. Australia is ranked ninth globally in the volume of scholarly outputs and sixth globally in citations. Australian scientists' proportion of the top 10% of cited publications involving international collaboration has risen more sharply than the OECD average.

It is indisputable – international collaboration is the norm for researchers in Australia. Ninety per cent of the top 50 cited papers from Australian authors in the Web of Science (2013–2023) were co-authored with overseas collaborators. Eighty per cent of Australian Research Council Discovery projects in STEM fields awarded in 2022 involved international collaborations.

Australia's patterns of international scientific collaborations are wide and diverse. We collaborate with almost every country in the world, with collaborations involving the US and the UK being particularly strong. Collaborations with China have grown in recent decades, and it is now among our most important international partners. Figure 2 shows how our scholarly outputs with China have increased steeply over the past decade.

Who does the research in Australia? Our higher education sector and research workforce are also highly international. In the natural and physical sciences, the number and proportion of overseas students has grown over the past two decades (Fig. 3). In 2021, 39% of natural and physical sciences postgraduate research student enrolments in Australia were overseas students.

Overall, international students represent 36% of Australia's postgraduate research students, who make up nearly a quarter of our research workforce and drive much of the original research conducted in Australia. In 2022–23, the top five citizenship countries for postgraduate research sector student visas granted were China (18%), India (9%), Saudi Arabia (9%), Sri Lanka (7%) and Bangladesh (7%).

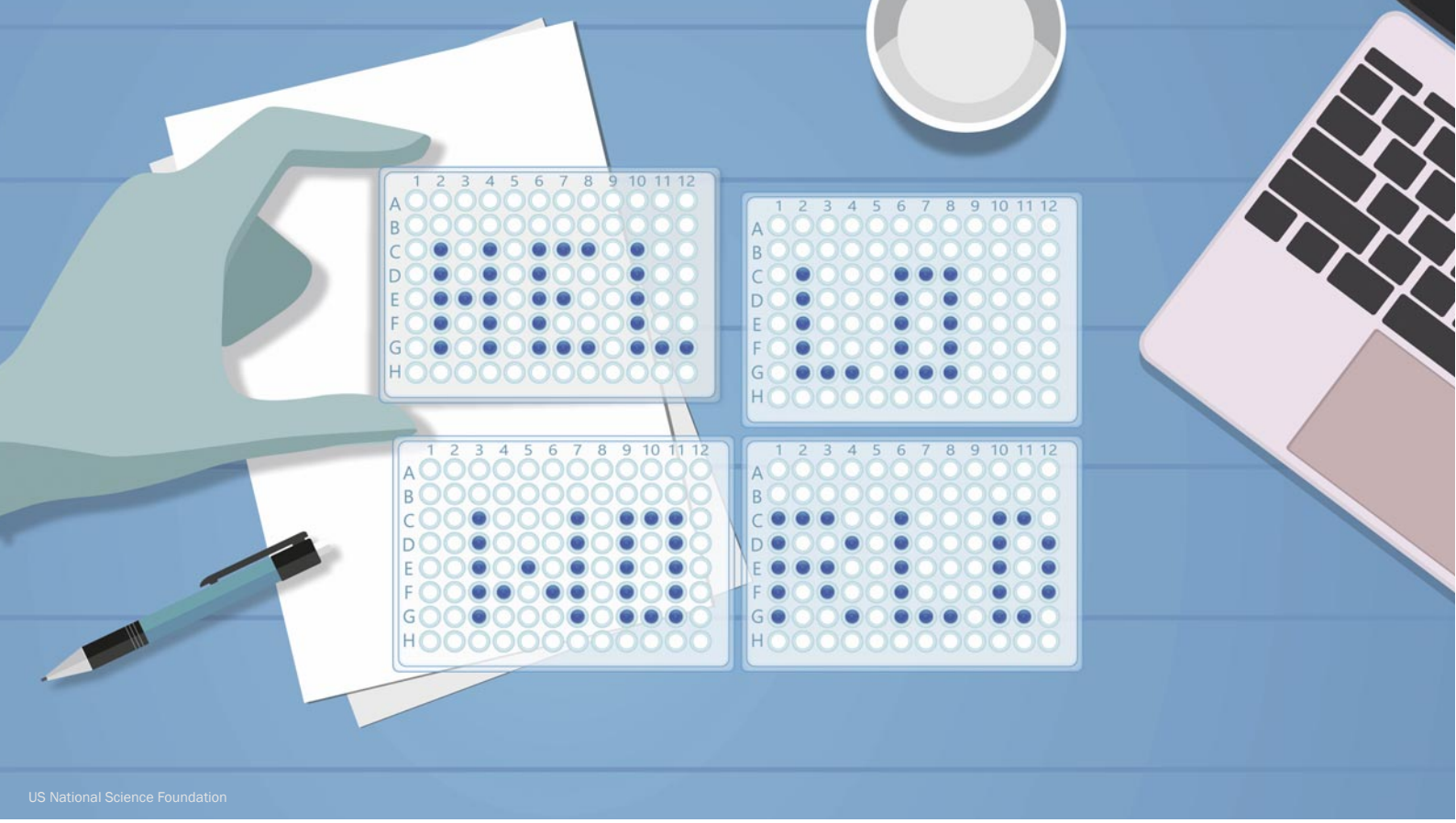
The "professional, scientific and technical" industry is the biggest user of temporary skilled visas. In 2020–21, universities sponsored 320 university lecturers and tutors. Let's not forget that universities rely on international student fees to remain financially viable.

The bottom line is that supporting international scientific collaboration is in Australia's national interest – perhaps just as much as strengthening our security is in our national interest. International research collaboration does provide challenges to national security, but it also contributes to maintaining it.

Today, the global science system is more vulnerable than it has ever been due to decisions taken by states as they respond to security challenges. So, we must tread carefully and with eyes wide open when presented with proposals that restrict our international scientific engagements. We must carefully weigh up the benefits and the costs of de-risking our research environment. And we must always take an evidence-informed approach.

There is too much at stake to do otherwise.

Professor Chennupati Jagadish AC PresAA FREng FTSE is President of the Australian Academy of Science. This is an abridged version of a keynote address to the International Science Collaborations in a Contested World National Symposium 2023 (https://youtu.be/qWOFmzggOU8?si=xAY7gPr_yJNuIbpS&t=930).



US National Science Foundation

Meet "Coscientist": your AI lab partner

BY **JASON STOUGHTON**

An AI-based system succeeds in planning and carrying out real-world chemistry experiments, showing the potential to help human scientists make more discoveries, faster.

In less time than it will take you to read this article, an artificial intelligence-driven system was able to autonomously learn about certain Nobel Prize-winning chemical reactions and design a successful laboratory procedure to make them. The AI did all that in just a few minutes – and nailed it on the first try.

''This is the first time that a non-organic intelligence planned, designed and executed this complex reaction that was invented by humans'', says Carnegie Mellon University chemist and chemical engineer Gabe Gomes, who led the research team that assembled and tested the AI-based system. They dubbed their creation ''Coscientist''.

The most complex reactions Coscientist pulled off are known in

organic chemistry as palladium-catalysed cross-couplings, which earned its human inventors the 2010 Nobel Prize for Chemistry in recognition of the outsized role those reactions came to play in the pharmaceutical development process and other industries that use finicky, carbon-based molecules.

Published in *Nature* (doi.org/10.1038/s41586-023-06792-0), the demonstrated abilities of Coscientist show the potential for humans to productively use AI to increase the pace and number of scientific discoveries, as well as improve the replicability and reliability of experimental results.

Putting Coscientist together

Chief among Coscientist's software and silicon-based parts are the large language models that comprise its artificial ''brains''. A large language model is a type of AI that can extract meaning and patterns from massive amounts of data, including written text contained in documents. Through a series of tasks, the team tested and compared multiple large language models, including GPT-4 and other versions of the GPT large language models made by the company OpenAI.

Coscientist was also equipped with several different software modules that the team tested first individually and then in concert.

''We tried to split all possible tasks in science into small pieces and then piece-by-piece construct the bigger picture'', says doctoral student Daniil Boiko, who designed Coscientist's general architecture and its experimental assignments. ''In the end, we brought everything together.''

The software modules allowed Coscientist to do things that all research chemists do: search public information about chemical compounds, find and read technical manuals on how to control robotic lab equipment, write computer code to carry out experiments, and analyse the resulting data to determine what worked and what didn't.

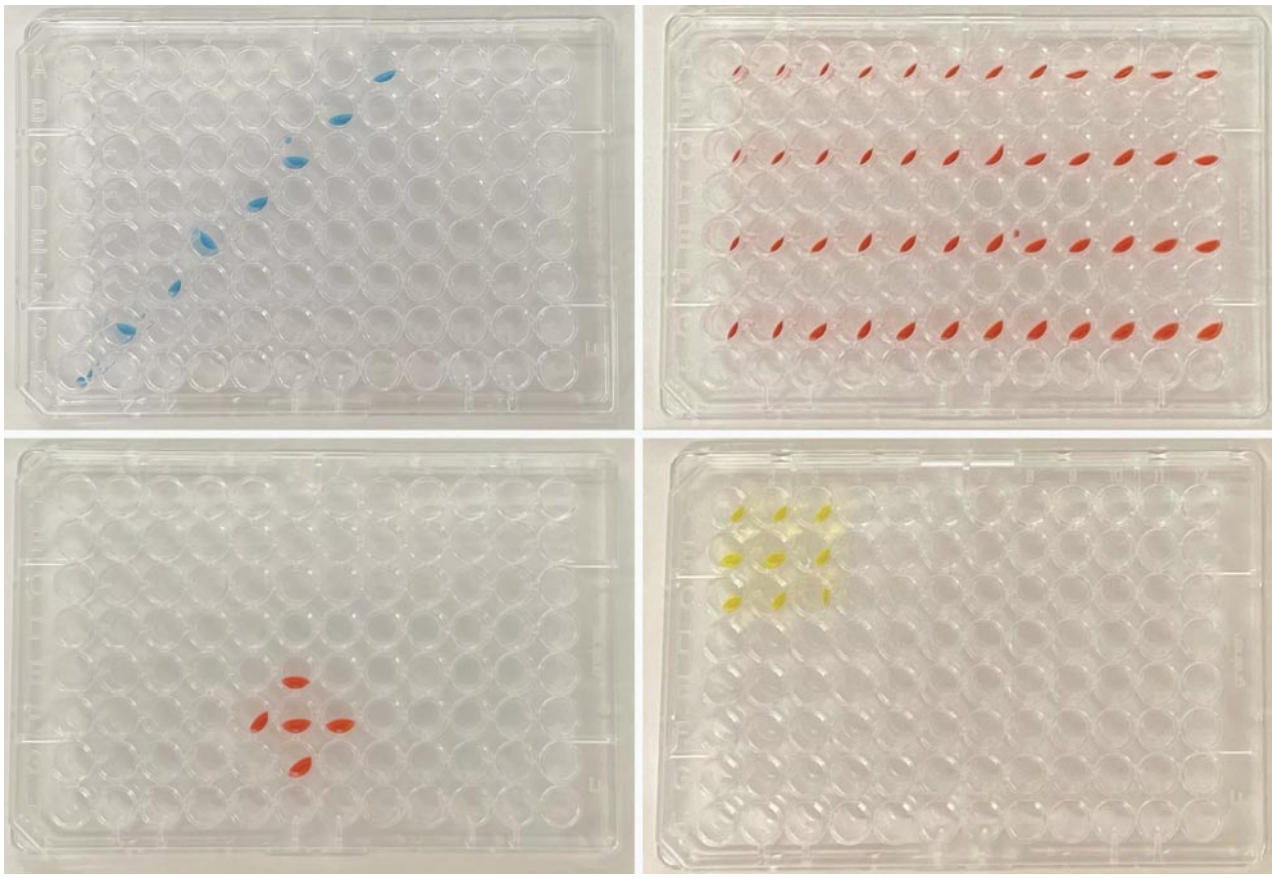
One test examined Coscientist's ability to accurately plan chemical procedures that, if carried out, would result in commonly used substances such as aspirin, acetaminophen and ibuprofen. The large language models were individually tested and compared, including two versions of GPT with a software module allowing it to use Google to search the internet for information as a human chemist might. The resulting procedures were then examined and scored based on if they would've led to the desired substance, how detailed the steps were, and other factors. Some of the highest scores were notched by the search-enabled GPT-4 module, which was the only one that created a procedure of acceptable quality for synthesising ibuprofen.

Boiko and doctoral student Robert MacKnight observed Coscientist demonstrating ''chemical reasoning'', which Boiko describes as the ability to use chemistry-related information and previously acquired knowledge to guide one's actions. It used publicly available chemical information encoded in the simplified molecular input line entry system (SMILES) format – a type of machine-readable notation representing the chemical structure of molecules – and made changes to its experimental plans based on specific parts of the molecules it was scrutinising within the SMILES data. ''This is the best version of chemical reasoning possible'', says Boiko.

Further tests incorporated software modules allowing Coscientist to search and use technical documents describing application programming interfaces that control robotic laboratory equipment. These tests were important in determining if Coscientist could translate its theoretical plans for synthesising chemical compounds into computer code that would guide laboratory robots in the physical world.

The Carnegie Mellon University Cloud Lab is a remotely operated, automated lab that gives researchers access to more than 200 pieces of scientific equipment.
Carnegie Mellon University

The software modules allowed Coscientist to ... search public information about chemical compounds, find and read technical manuals on how to control robotic lab equipment, write computer code to carry out experiments, and analyse the resulting data ...



Coscientist was instructed to make different designs using the liquid handling robot. Clockwise from top left are the designs it created in response to the following prompts: 'Draw a blue diagonal', 'Colour every other row with one colour of your choice', 'Draw a 3×3 rectangle using yellow', and 'Draw a red cross'. Carnegie Mellon University

Bring in the robots

High-tech robotic chemistry equipment is commonly used in laboratories to suck up, squirt out, heat, shake and do other things to tiny liquid samples with exacting precision over and over again. Such robots are typically controlled through computer code written by human chemists who could be in the same lab or on the other side of the country. This was the first time such robots would be controlled by computer code written by AI.

The team started Coscientist with simple tasks requiring it to make a robotic liquid handler machine dispense coloured liquid into a plate containing 96 small wells aligned in a grid. It was told to ''colour every other line with one colour of your choice'', ''draw a blue diagonal'' and other assignments reminiscent of kindergarten.

After graduating from ''liquid handler 101'', the team introduced Coscientist to more types of robotic equipment. They partnered with Emerald Cloud Lab, a commercial facility filled with various sorts of automated instruments, including spectrophotometers to measure the wavelengths of light absorbed by chemical samples. Coscientist was then presented with a plate containing liquids of three different colours (red, yellow and blue) and asked to determine which colours were present and where they were on the plate.

Since Coscientist has no eyes, it wrote code to robotically pass the mystery colour plate to the spectrophotometer and analyse the wavelengths of light absorbed by each well, thus identifying which colours were present and their location on the plate. For this assignment, the researchers had to give Coscientist a little nudge in the right direction, instructing it to think about how different colours absorb light. The AI did the rest.

Coscientist's final exam was to put its assembled modules and training together to fulfil the team's command to ''perform Suzuki and Sonogashira reactions'', named after inventors Akira Suzuki and Kenkichi Sonogashira. Discovered in the 1970s, the reactions use the metal palladium to catalyse bonds between carbon atoms in organic molecules. The reactions have proven extremely useful for producing new types of medicine that treat inflammation, asthma and other conditions. They're also used in organic semiconductors in organic light-emitting diodes found in many smartphones and monitors. The breakthrough reactions and their

broad impacts were formally recognised with a Nobel Prize jointly awarded in 2010 to Suzuki, Richard Heck and Ei-ichi Negishi.

Of course, Coscientist had never attempted these reactions before. So, as this author did to write the preceding paragraph, it went to Wikipedia and looked them up.

Great power, great responsibility

''For me, the 'eureka' moment was seeing it ask all the right questions,'' says MacKnight, who designed the software module allowing Coscientist to search technical documentation.

Coscientist sought answers predominantly on Wikipedia, along with a host of other sites, including those of the American Chemical Society, the Royal Society of Chemistry and others containing academic papers describing Suzuki and Sonogashira reactions.

In less than four minutes, Coscientist had designed an accurate procedure for producing the required reactions using chemicals provided by the team. When it sought to carry out its procedure in the physical world with robots, it made a mistake in the code it wrote to control a device that heats and shakes liquid samples. Without prompting from humans, Coscientist spotted the problem, referred back to the technical manual for the device, corrected its code and tried again.

The results were contained in a few tiny samples of clear liquid. Boiko analysed the samples and found the spectral hallmarks of Suzuki and Sonogashira reactions.

Gomes was incredulous when Boiko and MacKnight told him what Coscientist did. ''I thought they were pulling my leg'', he recalls. ''But they were not. They were absolutely not. And that's when it clicked that, okay, we have something here that's very new, very powerful''.

Gomes is one of several researchers providing expert advice and guidance for the US government's efforts to ensure AI is used safely and securely, such as the Biden administration's October 2023 executive order on AI development.

From left to right: Robert MacKnight, Gabe Gomes and Daniil Boiko. Carnegie Mellon University

Accelerating discovery, democratising science

Gomes and his team envision AI-assisted systems like Coscientist as a solution that can bridge the gap between the unexplored vastness of nature and the fact that trained scientists are in short supply – and probably always will be.

Human scientists also have human needs, like sleeping and occasionally getting outside the lab, whereas human-guided AI can ''think'' around the clock, methodically turning over every proverbial stone, and checking and rechecking its experimental results for replicability. ''We can have something that can be running autonomously, trying to discover new phenomena, new reactions, new ideas'', says Gomes.

''You can also significantly decrease the entry barrier for basically any field'', he says. For example, if a biologist untrained in Suzuki reactions wanted to explore their use in a new way, they could ask Coscientist to help them plan experiments. ''You can have this massive democratisation of resources and understanding'', he explains.

In less than four minutes, Coscientist had designed an accurate procedure for producing the required reactions using chemicals provided by the team.

There is an iterative process in science of trying something, failing, learning and improving, which AI can substantially accelerate. ''That on its own will be a dramatic change'', says Gomes.

Jason Stoughton is Staff Associate for Science Communications at the US National Science Foundation.

Congratulations to the 2023 RACI National Awards recipients.

Masson Memorial Award

For the pursuit of further studies in Chemistry, in memory of Sir David Orme Masson

Mr Theo Ellingsen,
University of Tasmania

At the time of being awarded the Masson Memorial Award for 2023, I was an Honours student pursuing a Bachelor of Science in Chemistry at the University of Tasmania. My research into my PhD will continue to centre on organic radical polymers for portable energy storage, aiming to address the growing demand for sustainable alternatives to lithium-ion batteries. By developing metal-free, adaptable materials that are easily recyclable, our work contributes to reducing environmental impact and reliance on traditional battery technologies.

The highlights of my academic journey include participating in two summer research projects and co-founding the Tasmanian University Chemistry Club, where I served as Co-President until November 2023. Facilitating the club's growth and fostering a social community for chemistry students was immensely fulfilling.

Outside academia, I enjoy playing guitar, spending quality time with loved ones, and caring for my pets.

My goal in the chemistry profession is to contribute to environmentally conscious technologies, ultimately lessening the environmental impact of industrial and consumer practices. My involvement with RACI includes organising the UTAS Chemistry Quiz Night and participating in accreditation processes, reflecting my commitment to fostering collaboration within the chemistry community.

RACI Postgraduate Student Travel Award

To assist postgraduate student members of the Institute to travel professionally from their home institution

Dr Diana Zhang,
University of New South Wales

As a recently awarded PhD graduate, I previously held roles as a Fulbright and Scientia Scholar at the University of NSW, emphasising my commitment to analytical chemistry. My work centres on enhancing disease diagnostics through mass spectrometry and machine learning. Inspired by Joy Milne, who can smell Parkinson's disease, I am dedicated to early disease detection by analysing bodily chemicals.

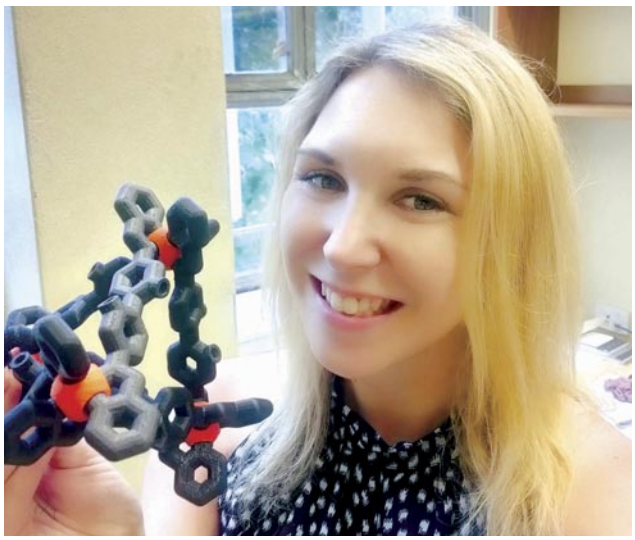
A standout moment was my 2022 Fulbright experience at Boston University, collaborating with the Kolachalama Lab to develop an AI tool detecting Parkinson's, 15 years before diagnosis, with 96% accuracy. Published in *ACS Central Science*, this exemplifies the potential impact of cross-disciplinary collaboration.

Beyond chemistry, I am fervent about inspiring young scientists, supporting postgraduates, and translating research into commercial products. As a professional musician, avid traveller and Arts sector advocate, I strive for a global impact.

Involvement with RACI includes panel speaking and advocating for members as a Science & Technology Australia Board Director. My goal is to see my research positively affect people worldwide, particularly those with Parkinson's disease, leading to improved quality of life.

Rennie Memorial Medal

For major research contributions to a field of chemistry by a scientist with no more than 8 years' experience post PhD



Dr Lauren Macreadie,
University of New South Wales

I am currently a Scientia Senior Lecturer and an ARC DECRA Fellow at the University of NSW, affiliated with the Department of Science in the School of Chemistry. My work is focused on addressing environmental CO_2 levels using porous materials, offering innovative solutions for fuel-driven separation methods and selective carbon dioxide capture.

A standout moment in my career was attending the Nobel Symposium on metal–organic frameworks in Sweden, which provided a unique opportunity to learn from and network with leaders in our fields.

Outside of chemistry, I cherish exploring Australia and New Zealand, particularly their wine regions and national parks.

If I could leave one mark on the chemistry profession, it would be demonstrating the diverse career possibilities within the field, successfully navigating across industry, government and academia. My involvement in RACI includes serving as Treasurer for the Supramolecular Division, NSW Representative for the Inorganic Division, and chairing the RACI Supramolecular Division Symposium in 2024. Additionally, I contribute to various committees and groups, such as the Metal–Organic Frameworks – International Commission, am a SCANZ Councillor, an Australasian representative of the RSC Porous Materials Interest Group, and a member of the User Advisory Committee at the Australian Synchrotron.

Associate Professor Christoph Nitsche,
Australian National University

As an associate professor and ARC Future Fellow at the Australian National University, my research bridges organic, medicinal and biological chemistry. Focused on biocompatible modifications of peptides and proteins, I strive to develop selective chemical reactions crucial for bioconjugation and drug discovery. This work is pivotal for advancing next-generation peptide- and protein-based drugs and has already contributed to the discovery of antiviral agents.

A standout moment occurred in 2017 when I uncovered bismuth's potential for selective protein modification, sparking a new and exciting research direction. Expanding on this, my group has utilised bismuth to craft constrained peptides, actively broadening its applications in drug discovery and chemical biology.

Outside chemistry, I share my passion for music with my children, having played the piano and guitar. Reading, gardening, hiking and long beach walks enrich my life.

My aspiration in the chemistry profession is to break down traditional boundaries, unleashing the full potential of the periodic table for translational research. Currently, I contribute to RACI as the ACT representative on the Medicinal Chemistry and Chemical Biology divisional committee, actively participating in conferences and events.

RACI Chemistry Educator of the Year Award

Early career award to recognise and encourage development in scholarly teaching practice

Dr Alexandra Yeung,
Curtin University

I am a senior lecturer at Curtin University, specialising in chemistry education, with a focus on science education more broadly. My work is crucial in improving students' perceptions and understanding of chemistry, particularly through blended learning and active learning activities. Investigating ways to enhance students' reflection and metacognitive skills is a key aspect of my research, conducted rigorously to benefit a wide audience.

A standout moment in my career was leading the implementation of electronic laboratory notebooks in first-year chemistry at Curtin University. Being among the first in Australia to use electronic laboratory notebooks for teaching, I have become a leader in this area, supporting uptake at my institution and across Western Australia.

Outside of chemistry, I am a proud mother of two young children, and our family enjoys exploring the outdoors and taking sunset walks along the port in Fremantle, Western Australia.

If I could leave one mark on the chemistry profession, it would be to inspire students to enjoy and understand chemistry while being an inclusive and motivating leader in science education. My involvement with RACI spans from my student days to serving as secretary of the Chemical Education Division and contributing to the International Conference on Chemical Education 2018. I am dedicated to fostering an environment where all colleagues feel trusted, valued and supported.

Distinguished Fellowship

Awarded in recognition of highly distinguished contributions to the profession

Emerita Professor Mary Garson,
University of Queensland

As an emerita professor at the University of Queensland, I have had a 30-year research career dedicated to exploring the chemistry of marine animals, specifically sponges and molluscs. Uncovering the small organic molecules that provide advantages to these underwater creatures in their competition for space and food has been a fascinating journey. Observing the vibrant marine life, I marvel at their use of natural chemicals for self-protection against predators.

A recent standout moment in my career is the election as Vice President/President-elect of the International Union of Pure and Applied Chemistry (IUPAC) for 2024–25, with the honour of assuming the presidency for 2026–27. As the second Australian woman to hold this global leadership role in IUPAC's 104-year history, it is a privilege to represent Australian chemistry.

Beyond chemistry, my interests include classical music and exploring Italy's cultural heritage and art.

My lasting mark on the profession is the creation and global impact of the Global Women's Breakfast, highlighting women's contributions to chemistry and fostering mentoring and networking. Serving as Queensland Branch President and Chair of the International Relations Committee in the mid-90s, I have contributed significantly to RACI's international engagements. I also proudly have a marine flatworm named after me, *Maritigrella marygarsonae*.

Leighton Memorial Medal

Awarded in recognition of eminent services to chemistry in Australia

Emeritus Professor David Brynn Hibbert, Honorary Dean of Emeriti University of New South Wales

As the Honorary Dean of Emeriti at the University of NSW, I reflect on a distinguished career that had significant focus on the discipline of analytical chemistry. My contributions include measuring the chemical world, naming new elements, and shaping the International System of Units through active involvement with the International Union of Pure and Applied Chemistry.

As an expert witness in domains like drugs, sports doping and murders, I have applied analytical expertise to address real-world challenges. Achieving the position of professor of analytical chemistry at 36 in 1987 is a notable highlight, alongside the recognition of my 2019 work on cobalt in horse racing as "high impact" by the Australian Research Council Excellence in Research for Australia. In 2023, I completed the IUPAC Orange Book, a 14-year project highlighting commitment to advancing analytical chemistry (see September–November 2023 issue, p. 36).

Beyond chemistry, my social engagements, including presidency at the Beefsteak and Burgundy Club, and active roles in the Royal Society of New South Wales, add depth to my retired life.

While an element may not bear my name, I take pride in a lasting contribution to analytical chemistry's advancement and recognition. In the RACI community, I chaired the NSW Analytical Group and the Computers in Chemistry Group, and co-chaired INTERACT 2002 in Sydney.

Weickhardt Medal for Distinguished Contribution to Economic Advancement

For distinguished contribution to economic advancement through work in chemistry

Professor Bernard Flynn, Monash University

As a professor of medicinal chemistry at Monash University and the CEO and co-founder of Cincera Therapeutics and Ankere Therapeutics, my focus lies in drug discovery, particularly in developing therapies for metabolic and respiratory diseases. Notably, I have led the discovery and development of two clinical candidates, addressing cancer and anxiety disorders, including PTSD.

Beyond the chemistry realm, I find joy in playing veterans Aussie Rules football, camping, hiking and spending time with my family.

If I could leave a lasting mark on the chemistry profession, it would be the development of a life-saving drug therapy for fatal chronic or infectious diseases. My involvement with RACI includes serving as a former committee member and Treasurer of the RACI Medicinal Chemistry and Chemical Biology Division (2004–11), chairing the Organising Committee for the Organometallics Symposium at the RACI Congress in Adelaide 2014, and contributing to various other RACI conference organising committees.

Fensham Medal for Outstanding Contribution to Chemical Education

Recognises outstanding contributions to the teaching of chemistry and science in general over an extended period

Adjunct Professor Roy Tasker,
Western Sydney University

I am honoured to serve as Adjunct Professor of Chemistry Education at Western Sydney University and Chief Scientific Adviser for the Planet Ark Environmental Foundation. My work is twofold: I pioneer molecular-level multimedia visualisations to deepen students' understanding of chemistry, enabling them to bridge the gap between abstract symbols and observable phenomena; and simultaneously, I address the crucial issue of managing poly- and per-fluoroalkyl substances, emphasising their utility in consumer items while advocating for timely environmental regulation.

A standout moment in my career occurred in 2011 when I received the Prime Minister's Award for Australian University Teacher of the Year at the Sydney Opera House.

Beyond chemistry, I find solace in body surfing, immersing myself in the sea's rhythm.

If I could leave a lasting mark on the chemistry profession, it would be fostering wonder about molecular structures in living systems and inspiring young minds to grasp molecular-level concepts. I am proud of my involvement in the RACI chemistry education community and remain committed to promoting public understanding of the molecular world's significance.

Margaret Sheil Leadership Award

For recognition of efforts to inspire and mentor junior female chemists and/or work towards a more equitable workplace

Professor Debra J. Bernhardt,
University of Queensland

I currently hold the position of ARC Australian Laureate Fellow and Professor at the University of Queensland.

My research delves into theoretical and computational molecular science, particularly focusing on non-equilibrium systems. These encompass a broad range, from systems with changing properties over time to those influenced by constant fields or mechanical forces.

My work contributes to the development of fundamental theory, especially for systems far from equilibrium. I am proud of moments when understanding complex phenomena has illuminated our research, such as our breakthrough in extending fluctuation theorems to systems coupled with surroundings.

Beyond my academic pursuits, I cherish spending time with family, walking my dog, and contributing as a community bushcare volunteer.

If I could leave a mark on the chemistry profession, it would be fostering opportunities for the next generation to make a positive societal impact and emphasising the importance of foundational science for future technologies. My involvement with RACI includes chairing the 2022 RACI National Congress and various roles in symposium organisation and branch activities.

Welcome Award

Established to honour and welcome a chemist who is new to Australia

Professor Adam Fraser Lee,
Griffith University

I proudly serve as Professor of Sustainable Chemistry at Griffith University, affiliated with the Centre for Catalysis and Clean Energy and the School of Environment and Science.

My research team focuses on developing environmentally sustainable chemical processes, utilising catalysts for renewable resource-based fuel and high-value molecule production. This work is crucial for addressing climate change and ensuring a sustainable transition from fossil fuels.

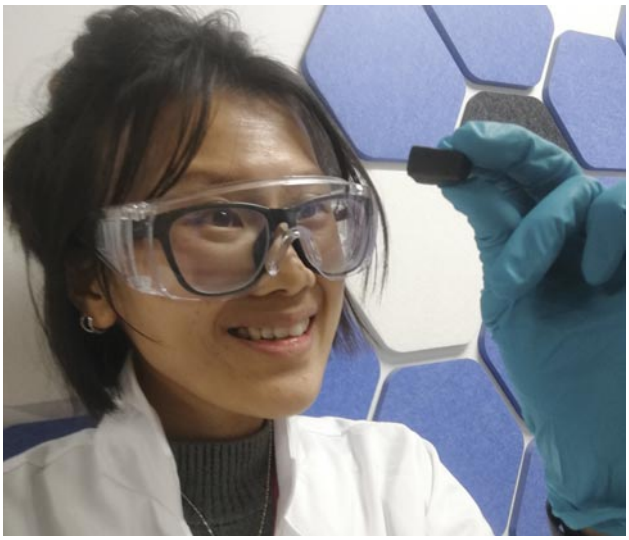
Throughout my academic journey, one standout moment was the exhilarating discovery of the first real-time surface chemical reaction using X-ray photoelectron spectroscopy.

Beyond chemistry, I am an avid wildlife photographer and enjoy exploring Australia's natural wonders. In the chemistry profession, I aspire to foster a holistic view of catalysis and promote mental health awareness.

My involvement with RACI includes being a Fellow, contributing to the Green and Sustainable Chemistry National Group, and organising the inaugural GASC Conference in 2023. I also actively participate in RACI events and contribute as the Editor-in-Chief of *Materials Today Chemistry*, emphasising the collaborative spirit that defines my scientific endeavours.

Catalyst Award

Established to recognise an early career chemist – for outstanding innovation in applied chemistry in the workplace



Dr Pei Lay Yap,
University of Adelaide

As a postdoctoral research fellow at the ARC Research Hub for Advanced Manufacturing with 2D Materials (AM2D) at the University of Adelaide, I delve into the realm of surface chemistry and materials engineering.

My research centres on modifying 2D materials, notably graphene, for environmental applications such as water purification and CO_2 capture. This work is vital in developing multifunctional graphene-related 2D materials with controlled surface chemistry to address global environmental challenges.

A standout moment in my career was leading an international interlaboratory comparison study on quality control and standardisation of graphene-related 2D materials, contributing to the development of standardised protocols. Despite challenges during the peak of the COVID-19 pandemic, we successfully completed the project, resulting in a significant impact on global graphene research.

Outside of my research, I find solace in travel, exploring new paths that inspire creativity and innovation. If I could leave one mark on the chemistry profession, it would be inspiring young individuals, particularly women, to pursue STEM careers.

My involvement with RACI includes contributing to the International Chemistry Quiz and being honoured with the Cornforth Medal for outstanding achievements in chemistry. I aim to continue fostering diversity and inclusivity in STEM fields for the future.

Cornforth Medal

For the most outstanding PhD thesis in chemistry or a related field, in the previous year

Dr Asja Kroeger,
Flinders University

I am currently a postdoctoral fellow at the Australian National University and hold the position of associate lecturer at Flinders University, working within Professor Michelle Coote's research group.

To gain an understanding of the relationship between structure, function and reactivity for the rational design of new processes or materials is a core aim in chemistry. Increasingly, modern computational chemistry methods allow for insights into those relationships to be gained prior to experiment or in synergistic collaboration. As a small part of this much larger endeavour, my PhD thesis focused on exploring the possibility for catalysis to be driven by the typically weak π-stacking interactions (π–π catalysis).

Throughout my PhD, I was fortunate to work in a supportive environment, contributing to the Western Australia Computational Chemistry conferences and serving as college president.

Beyond chemistry, I find solace in hiking and exploring Adelaide's scenic surroundings.

If I could leave a lasting mark on the chemistry profession, I aspire to contribute to making the discipline more accessible, particularly in terms of training and conferences. As a long-time RACI member, I have presented at conferences, participated in webinars, and organised events like the 2020 RACI Physical Chemistry Student Conference and the integration of the Western Australia Computational Chemistry conferences with the RACI Phys Chem Summer Festival in 2021. Receiving the Postgraduate Student Travel Bursary allowed me to engage with diverse perspectives at PacifiChem, leaving a lasting impact on my academic journey.

H.G. Smith Memorial Award

For major research contributions to a field of chemistry over the past 10 years

Professor Michael Kassiou,
University of Sydney

I hold the position of Professor of Medicinal Chemistry and NHMRC Principal Research Fellow at the University of Sydney, where I also serve as the Academic Director of the Drug Discovery Initiative.

My pioneering work in medicinal chemistry focuses on understanding drug–protein interactions in brain chemistry, revealing crucial insights for innovative translational research in drug discovery.

A standout moment in my career is the graduation of my first PhD student, embodying the essence of contributing to others' success.

Beyond the chemistry realm, I find joy in playing soccer with my son, nurturing his potential.

If I could leave one mark on the chemistry profession, it would be to inspire courage and self-challenge, guided by the principles of novelty, truth and relevance in research. I proudly served as Chair of the RACI Medicinal Chemistry and Chemical Biology Division from 2013 to 2016, recognising that in science, collective efforts shape meaningful journeys.

Rita Cornforth Lectureship

Awarded to an outstanding female early career chemist

Dr Amandeep Kaur,
Monash University

I am honoured to serve as a lecturer and ARC DECRA Fellow at the Monash Institute of Pharmaceutical Sciences, Monash University.

My research focuses on developing fluorescent sensors that illuminate the intricacies of the biological world, serving as precise tools to unravel cellular processes, biomolecular interactions and disease mechanisms.

The practical impact of my work is evident in the commercialisation of redox sensors developed during my PhD, distributed globally and actively utilised by research groups worldwide.

Beyond the lab, I find fulfilment in volunteering at a Sikh Temple, contributing to the community kitchen, and indulging in crochet, with plans to launch a business.

My aspiration in the chemistry profession is to transform sensor breakthroughs into tangible outcomes, revolutionising health monitoring and disease diagnostics globally.

I have been actively involved with RACI, serving as Chair of the RACI NSW Women in Chemistry group, and receiving recognitions such as the RACI Nyholm Youth Lectureship. Throughout my journey, I am grateful for the guidance of amazing mentors, who inspire both knowledge-sharing and a people-centric approach.

New Fellow

Professor Kourosh Kalantar-Zadeh is Head of the School of Chemical and Biomolecular Engineering at the University of Sydney. He is also one of the Australian Research Council Laureate Fellows of 2018. Kalantar-Zadeh was a professor of chemical engineering at the University of New South Wales, and prior to that, a professor of electronic engineering at RMIT. He is involved in research in the fields of analytical chemistry, materials sciences, gastroenterology, electronics and sensors, and has co-authored more than 500 highly cited scientific papers.

Kalantar-Zadeh is a member of the editorial boards of journals, including *ACS Applied Nano Materials* (associate editor), *ACS Sensors*, *Advanced Materials Technologies*, *Nanoscale*, *Applied Surface Science* and *ACS Nano*. Kalantar-Zadeh is best known for his work on ingestible sensors, liquid metals and two-dimensional semiconductors. He led his group to the invention of an ingestible chemical sensor: the human gas sensing capsule, one of the breakthroughs in the field of medical devices.

Kalantar-Zadeh has received several international awards for his scientific contributions, including the 2017 IEEE Sensor Council Achievement, 2018 American Chemical Society Advances in Measurement Science Lectureship awards, and the 2020 Robert Boyle Prize of the Royal Society of Chemistry. In addition to being a Fellow of RACI, Kalantar-Zadeh is a Fellow of the American Association for the Advancement of Science, the Institution of Engineering and Technology (UK), the Royal Society of Chemistry (UK) and the Royal Society of New South Wales.

Before completing his PhD, Kalantar-Zadeh worked as a professional illustrator and cartoonist. His sketches frequently appeared in magazines such as *The New Yorker*, and he received several international awards for his artwork.

Chemistry for everyone: the RACI Inclusion and Diversity Framework

Although inclusion and diversity (I&D) is accepted by organisations around the world as being of critical importance, most organisations have a long way to go to achieving full diversity and a culture of inclusion and belonging. RACI recognises that it is no different.

RACI has a long-standing policy that outlines its commitment to promoting inclusivity and transparency within a culture of mutual respect and to improving diversity. Progress, particularly in relation to gender equity, has been made. But how much progress? What areas are we falling behind in? And how does RACI compare to other organisations?

In response to such questions, in October 2023, the RACI Board approved a new I&D Framework for promoting equity and I&D across all its operations and activities. In establishing this, the RACI Board acknowledged that achieving diversity and inclusion is an organisational priority. Such a journey requires us to prioritise and self-assess outcomes and impact and be transparent in reporting what progress has been made (or not!).

But what does success look like for RACI? To answer this, the RACI Board has approved its Inclusion and Diversity Strategic Goals 2023–2028 (see box below), which outlines aspirational measures of success across four key areas of:

- leadership
- diversity targets
- inclusion
- communication and engagement.

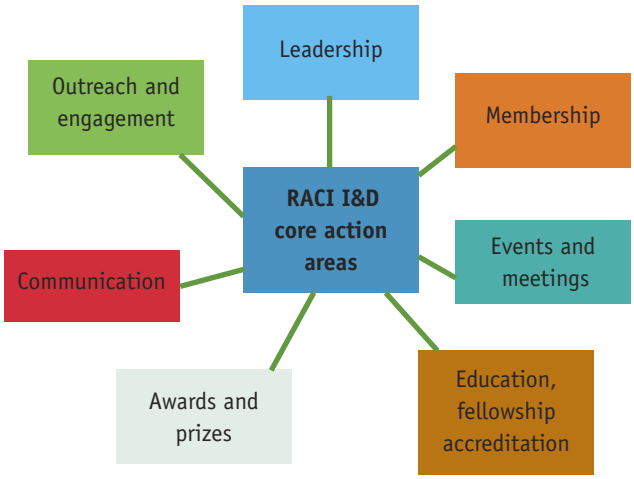


Fig. 1. RACI's I&D Framework core action areas for targeted action.

These measures and targets allow for focused actions across the framework's core action areas.

A further part of the framework development saw RACI conducting a membership survey to establish baseline data and information about RACI's current I&D status. The I&D survey was the first of its kind for RACI and was conducted from July to August 2022. The survey received 141 responses (4% of the membership). The low response rate is mainly attributed to a lack of a coordinated communication strategy and low leadership visibility. As the aim was to establish some baseline

RACI Inclusion and Diversity Strategic Goals 2023–2028

1 Leadership

The RACI Board and Executive lead I&D initiatives, ensuring transparent reporting on progress towards achieving diversity and inclusivity goals across the activities of the organisation. The Board, through RACI's leadership groups, sets and promotes the culture of the Institute.

2 Set diversity targets

- All leadership groups in RACI and all event programs and mentoring and other activities will comprise 40% women, 40% men and 20% of any gender. This aims to interrupt gender bias across leadership groups and all talent processes.
- Under-represented diversity areas will be increased in leadership groups, and more widely in the membership, with an aspiration of reflecting the diversity demographics of Australia's STEM workforce.
- Membership will reflect the diverse employment sectors for chemical sciences, namely teachers, academics, researchers (publicly funded research organisations), government and industry sectors.
- Representation of students and/or early career chemical scientists will be widely established within RACI activities.

3 Inclusion

RACI Inclusion and Belonging membership surveys will show that individual differences are valued within a culture of respect, openness and belonging across all of RACI operations and activities.

4 Communication and engagement

- Through targeted communications and leadership roles, awareness of the RACI I&D Policy and Framework will be enhanced across the membership.
- RACI will engage with the Australian chemical sciences sectors to promote equity, diversity and inclusion, including in sharing RACI's journey and learnings.
- Outcomes and performance on I&D actions will be widely and transparently reported, including to the broader community.

information, many valuable lessons have been learnt and, indeed, inform both the design and running of future surveys as well as the selection of the framework's core action areas (Fig. 1).

About the framework

The framework provides a systemised approach to RACI's efforts to ensure a diverse membership and an inclusive culture, using an evidence-based approach that measures outcomes and impact over time. Using a progression model framework takes into account that RACI has already embarked on gender equity, diversity and inclusion action pathways, albeit with varying results.

RACI's I&D Framework is modelled on an I&D framework for professional membership societies and learned academies (including the Royal Society of Chemistry) developed in the UK under the leadership of the Science Council and the Royal Academy of Engineering. This is important because the international aspect of our framework provides an opportunity for RACI to benchmark its performance against progress in other countries.

The framework enhances our ability to connect with and learn from other organisations in the sector, both nationally and internationally. Further, it allows us to effectively contribute to national efforts to promote an equitable, diverse and inclusive science, technology, engineering and mathematics sector in general, and chemical sciences in particular.

The framework establishes overarching strategy principles (see box this page) for each core action area and also spells out how:

- data is collected, used and reported while protecting members' privacy
- authority is allocated across our various volunteer-run organisational structures
- RACI will be accountable.

The framework will provide a valuable mechanism to structure conversations across the membership about performance and progress, identifying our strengths as well as areas requiring further development, and planning next steps. Noting RACI is a voluntary-based organisation, we will focus on delivering robust outcomes while minimising administrative burden.

We look forward to sharing our journey and will publish our diversity data and conduct inclusion and belonging reports biennially.

Want to know more?

For more information, visit www.raci.org.au.

High-level summary of key strategy principles of the framework

Leadership and governance
The Board is responsible for leading policies and actions that reflect a culture of equity, diversity and inclusion and sets targets for all leadership groups across the Institute.

Membership
Increasing under-represented groups in our membership is a priority, including culturally appropriate engagement with Indigenous scientists.

Events and meetings
Our I&D policies and principles are to be reflected across all RACI events, conferences and meetings.

Education, training and accreditation
We will include a diversity and inclusion overlay in our Accreditation Board and its activities; our schools' programs (e.g. ensuring diversity in our scientist profiles, trainers and other educational materials) and our support of early career chemists (e.g. mentoring and other related activities).

Awards and prizes
Commitment to equity, diversity and inclusion applies to all aspects of our awards and prizes programs. RACI will actively seek nominations from candidates from diverse backgrounds and career pathways. Assessment panels must reflect diversity and operate in an inclusive manner.

Communication
We will communicate our diversity and inclusion policies and principles to our membership and seek their input in achieving our goals.

Outreach and engagement
We will enhance activities that seek to engage and increase interest and widen participation in chemical sciences broadly and engage in broader policy input on issues (e.g. on women in STEM and diversity and inclusion in STEM government programs).

We will engage with international counterparts on our I&D policies and activities as part of best practice benchmarking.

Monitor and measure
We will be accountable for our policies and actions by publicly reporting our progress and impact under our I&D Framework.

Dr Margaret Hartley FTSE FRACI CChem MAICD (Co-Chair (2023, 2024) RACI Inclusion and Diversity Committee) is an advisor and a consultant, and an independent non-executive director of Wintermute Biomedical Inc. **Associate Professor Lars Goerigk** MRACI CChem (Co-Chair (2022, 2023) RACI Inclusion and Diversity Committee) is at the Melbourne Centre for Theoretical and Computational Chemistry, School of Chemistry, University of Melbourne.
Dr Kathleen Mullen MRACI CChem (Co-Chair 2024 RACI Inclusion and Diversity Committee) is a research group leader and senior lecturer in chemistry at the Queensland University of Technology.

The development of the Framework and related activities was undertaken by the RACI Board's I&D Committee (RIDC) members. RIDC's role is to ensure inclusive practices that seek to increase diversity representation, increase engagement with under-represented groups in culturally appropriate ways and support the RACI Board in building a culture that promotes inclusivity and respect.

Vale Frederick Charles James (1929–2023)

Inaugural Dean of the Faculty of Applied Sciences, RMIT

Anyone who studied Chemistry in the Department of Applied Chemistry at RMIT between 1954 and 1973 would remember Fred James with affection.

Fred joined the department as a lecturer in 1954 and was appointed senior lecturer in 1960, becoming head of department in 1963, in which role he served for 10 years. His specialisation was organic chemistry, in particular heterocyclic chemistry. He was an excellent lecturer and taught organic chemistry with great flair, almost always without notes. His enthusiasm for the subject was infectious.

Frederick Charles James was born on 20 February 1929 in Brunswick, Victoria. He attended the Brunswick North Primary School and later Brunswick Technical School, where he completed his Intermediate Technical Certificate in 1943. He began his study of Chemistry at Footscray Technical College. Since Footscray Technical College did not offer the diploma qualification, after two years Fred transferred to the Melbourne Technical College, where he completed two more years of study and was awarded the Melbourne Technical College Associate Diploma of Applied Chemistry. After further study and completion of the required industrial experience in the laboratory at Kraft Walker Cheese Co. in Port Melbourne, Fred received the Fellowship Diploma of Applied Chemistry.

Fred then enrolled in the Bachelor of Science (Chemistry) course at the University of Melbourne and went on to complete the Master of Science degree in 1954.

Fred met Joan Bennett while on a camping holiday at Wilson's Promontory. They married on 7 January 1955 and together had three children, Stephen, Wendy and Phillip.

Fred James had a long association with RACI and served it well. He had no hesitation in encouraging those attending his lectures to join RACI as Student Members, after explaining the benefits.

RMIT had hitherto been seen as a teaching-only institution by government, but Fred was committed to chemical research as an important adjunct to teaching. Following his appointment as head of department in 1963, he secured modest funds for research and the salary for a research assistant. Fred and his research assistant, H.-D. Krebs, researched and published on the chemistry of thienoisothiazoles.

Fred had a long association with RACI and served it well. He had no hesitation in encouraging those attending his lectures to join RACI as Student Members, after explaining the benefits. In 1960, Fred was appointed to an RACI committee chaired by Professor Bernard Ralph, investigating qualifications for RACI membership. The committee visited most academic chemistry departments in Australia, giving Fred valuable first-hand knowledge of Chemistry courses across the nation. He was elected a Fellow of RACI in November 1973.

He continued to serve on the Qualifications and Accreditation Committee for some years. Later, he was a member of the RACI Council (which preceded the RACI Board).

RMIT continued to evolve, and in 1973 the departments of Applied Chemistry and Applied Biology were combined administratively to become the School of Biological and Chemical Sciences. Fred was appointed Head of School. Four years later, the Faculty of Applied Sciences was created and Fred was appointed inaugural dean.

Fred retired on 24 April 1987 after a distinguished career at RMIT spanning 33 years. In retirement, Fred served for three years on the Hong Kong Council for Academic Accreditation.

I thank the James family for affording me the honour of writing Fred's obituary, and approving it for publication. I acknowledge the meticulous detail recorded by Peter H. Brady in his 2004 book *Avery's legacy, a history of the Department of Applied Chemistry, RMIT*, which has been invaluable for confirming facts and dates.

Fred James taught the writer Organic Chemistry, and became his mentor and lifelong friend.

Peter G. Lehman FRACI CChem

Vale John Bromly

Distinguished chemist in the gas industry

Dr John Bromly FRACI CChem passed away on 3 January 2024.

John joined the gas industry as a graduate chemist with the State Energy Commission of Western Australia in 1967, after completing a part-time Diploma in Pure Chemistry at Perth Technical College. He undertook postgraduate studies at the Western Australian Institute of Technology and gained graduate diplomas in Chemical Engineering, Chemistry and Electronic Instrumentation.

In 1987, he completed a Master of Engineering degree at the University of Western Australia, studying the production of carbon monoxide and nitrogen oxides in gas appliances. John then led an industry study that identified techniques to significantly reduce nitrogen oxides, and particularly nitrogen dioxide, emissions from space heaters. Principles identified in the research have been applied by manufacturers in the development of burners that produce reduced levels of nitrogen oxides.

This research was followed by a PhD at Murdoch University in 1991 titled "The formation of nitrogen oxides in gas combustion". This work allowed for the controlled use of unflued gas heaters in Western Australia, though ultimately these are expected to be phased out.

John worked for the SEC then AlintaGas for 34 years, retiring as Principal Scientist of the WA Gas Laboratory in 2001. This was followed by research positions at Curtin University and consulting work for government. He was the author or co-author of numerous publications, mostly in combustion science.

John was a perpetual student, held in high regard by his associates for his thoroughness and patience, in addition to his vast knowledge and unparalleled memory. John was recognised through awards, including:

- 1991 Australian Gas Association Silver Flame Award for work on "low NO_x" burners
- 2003 Centenary Medal for service to the gas industry and development of gas appliance testing standards
- 2004 Meritorious Award by the Gas Industry Association of Western Australia for long and distinguished service to the gas industry
- 2012 RACI Western Australia Branch A. McA. Batty Medal for contributions to the gas industry.

John is survived by his wife Loretta, daughters Melissa and Louise, and grandchildren Angus, Zara, Stella and Alex.

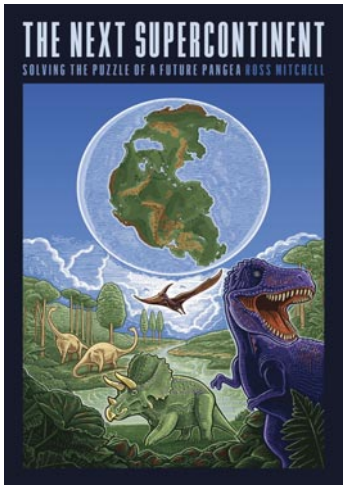
Melissa and Louise Bromly, and others

selim/Adobe

As your RACI member magazine, *Chemistry in Australia* is the perfect place to discuss chemistry issues and developments.

If you or a colleague have a story to tell that's of interest to professional chemists, pitch your idea to editor@raci.org.au.

Writers' guidelines are at chemaust.raci.org.au.



The next supercontinent: solving the puzzle of a future Pangea

Mitchell R., University of Chicago Press, 2023, hardback, ISBN-13 9780226824918, approx. $40, e-book, ISBN-13 9780226824925

If, like me, you are a devotee of Thomas Kuhn's *The structure of scientific revolutions*, you will greatly enjoy reading *The next supercontinent: solving the puzzle of a future Pangea*.

The book neatly encapsulates the revolution of ideas about plate tectonics and the slow but inexorable changes that have occurred, and continue to occur, over the four and a half billion years of the history of our planet. Yes, indeed, we are adrift on our earthly rafts on a sea of molten rock, and without a paddle! And it gets even worse: new land is being continuously thrust up and old land subducted; some oceans are expanding, others are shrinking. These massively energetic processes drive the movement of tectonic plates. When you throw in the need to preserve the angular momentum of the ovoid-shaped Earth, you might not be too surprised to learn that continental Australia has made a couple of short-term (geological) oscillations up towards the equator and back to preserve angular momentum.

What of supercontinents? There have been three supercontinents identified over the history of Earth: Colombia (about 1300 million years ago (Mya) in the Proterozoic eon), Rodinia (later in the Proterozoic, about 800 Mya) and Pangea (in the Phanerozoic eon, about 200 Mya). Their existence is firmly established with evidence obtained by geophysical technology and careful mapping and the "rules" regarding their formation and subsequent fragmentation are well understood. There were also structures called cratons and possibly also super cratons, dating back to the Archeon eon about 2500 Mya. These are nice, thick, very old crust, so take heart, central Australia has an almighty big craton that serves to confirm we are most unlikely to find ourselves falling through the crust to the roiling magma below!

What of other supercontinents? There is little if any evidence of anything prior to Colombia. For the future, there is general agreement that another supercontinent is on its way. For example, in the fullness of time, Australia will crash into India, the Mediterranean Sea will close, and a supercontinent may emerge encompassing Europe, China, Africa, India, Australia etc. This should cause us no concern. We are probably looking 200 million years into the future. It won't happen straight away, but it will happen eventually. As a species, we have missed the first three and we are well on the path to extinction a long time before the fourth. To borrow from Tennyson, "Men may come and men may go, but I [Earth] go on forever".

... in the fullness of time, Australia will crash into India, the Mediterranean Sea will close, and a supercontinent may emerge encompassing Europe, China, Africa, India, Australia etc.

Now, if you had sprouted this stuff about supercontinents and continental drift and cratons 60 or so years back, you might well have found yourself accused of fruit-loopery. There has, indeed, been a scientific revolution in the way Earth is viewed. Kuhn at work!

Author Ross Mitchell is a professor at the Institute of Geology and Geophysics of the Chinese Academy of Sciences in Beijing. In his research, he has worked with many of the pioneers and current people at the forefront of the study of supercontinents. The book is well written, in the first person, and well seasoned with anecdotes that bring people to life. You will even learn, as an aside, how the author lost the end of his thumb in remote central Australia. Concepts are clearly explained. All in all, the book is a great and very lucid review of some of the fascinating history of our planet. I enjoyed it immensely and learnt a lot from its pages.

R.J. Casey FRACI CChem HLM

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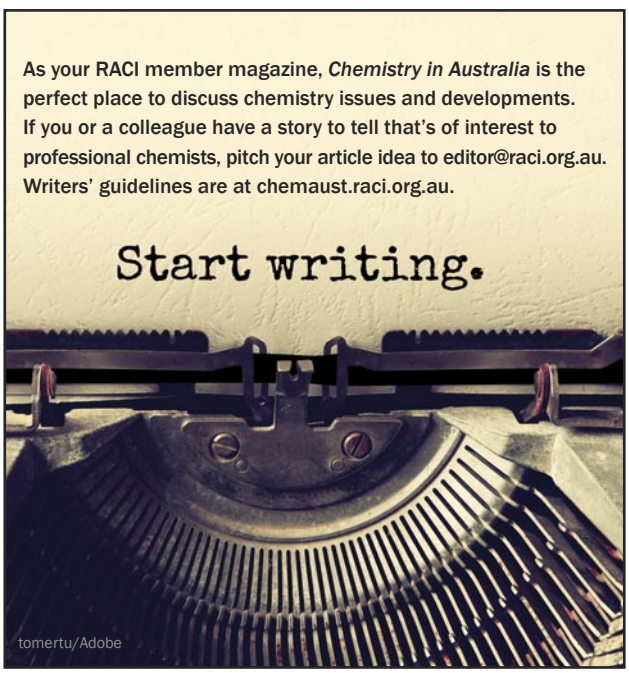


The renewables era: solving the skills bottleneck

Renewables developments have been growing rapidly around the world in recent years, but they are now encountering a bottleneck due to the lack of many relevant skills and jobs. The International Energy Agency reports that by 2030 there will be a global shortage of 7 million skilled workers that would be needed for the necessary climate and energy projects.

This skills shortage includes various disciplines, such as physical sciences, engineering, data science and mathematics. The required skills include a full diversity of levels from research scientists and engineers to relevant apprenticeships. Chemistry is a key field in the development of batteries, fuel cells, solar catalysis and electrolytic and photolytic processes required to produce green hydrogen. Renewables is a broad interdisciplinary research and development sector, in which scientists and engineers work in cooperative teams to achieve real success. The future of renewables will also require skills in innovation and business leadership.

The leading global renewables at present are solar, wind, hydro, tidal and green hydrogen (the last with no associated greenhouse gas emissions). Solar, wind and electric vehicles are leading the way. The economic tipping point for adopting green hydrogen internationally (including Australia) is US$2/kg (AU$3/kg). Once it is below that point, green hydrogen will become cheaper than existing industrial grey and blue hydrogen (with their associated greenhouse gases). The leading country in this race is China, which is currently producing green hydrogen at US$2.90/kg (AU$4.5/kg). Projections by MarketsandMarkets USA indicate that the tipping point for green hydrogen will be crossed in many advanced economies well before 2030.

audioundwerbung/iStockphoto

In October 2023, the Jobs and Skills Australia report addressed skills shortages in renewables, and identified workforce targets that Australia requires to achieve net-zero carbon. These targets include, first, 82% renewable energy generation in the National Electricity Market and 43% reduction of emissions below 2005 levels by 2030. The targets also require 450 000 renewables jobs in construction of clean energy production and transmission infrastructure, which is one-third of all jobs growth in Australia. The report notes that half of the existing electrical engineers in Australia were born overseas. The report also urges the reform of training and educational offerings and the creation of a more inclusive workforce. The Clean Energy Council has endorsed the recommendations of this 2023 report.

Intense international competition for skilled specialists will determine which countries dominate the early phases (until 2040) of the renewables transition. Various solutions to the bottleneck have been suggested, including more skilled migration, increasing the number of specialist higher education programs in renewables, and retraining existing fossil fuel workers in skills relating to renewables. A report from Scotland indicated that 80% of fossil fuel workers are keen to be retrained provided retraining is affordable for them.

The recent massive global investments in renewables have been driven mainly by the US and China, and mainly (75%) by the private sector. Investments have increased from $11.2 billion in 2012 to $21 billion in 2022. It has been reported that the US and China are each planning to invest at least $3 trillion in renewables over the coming decade. The International Energy Agency reports that global clean-tech investment needs to reach about $7.7 trillion a year by 2030. In 2023, world governments invested $2.6 trillion in clean energy, including renewable power, nuclear, grids, storage, low-emission fuels, efficiency improvements and end-use renewables and electrification.

The growth of the renewables transition internationally will require the involvement of universities and industrial training organisations. It will also require a strong culture of cooperative interdisciplinary development. Recent projections by researchers in Canada and Austria indicate that one billion climate-caused deaths will occur over the next century. The instinct for human survival will surely be a powerful incentive to establish a renewable economy by Australia and other countries.

Ralph Cooney ONZM, FRSNZ, FRACI CChem has had a science and innovation career bridging New Zealand and Australia. He was former University of Auckland Pro Vice Chancellor of the Tamaki Innovation Campus, Dean of Science, Head of Chemistry and Science Leader of several major national research programs.

What's the white stuff on my Easter chocolate, and can I still eat it?


Salino01/CC BY 3.0

The words "chocolate" and "disappointment" don't often go together.

But you may have experienced some disappointment if you've ever unwrapped the bright foil of an Easter egg to discover white, chalky chocolate inside. What is this white substance? Is it mould? Bacteria? Is it bad for you? Can you still eat it?!

The answer is yes, you can! It's called "bloom" and it's caused by fats or sugar from the chocolate. To understand why it forms, and how to avoid it forming, we need to consider the chemistry of chocolate.

The right stuff

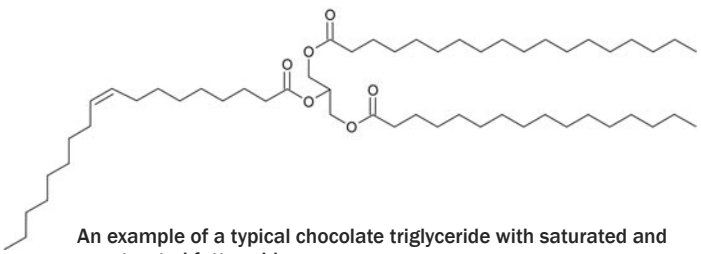
Easter egg chocolate is made up of a relatively small number of ingredients: cacao beans, sugar, milk solids, flavourings and emulsifiers to keep it all mixed together.

Fermenting and roasting cacao beans triggers many chemical reactions, which develop delicious flavours. Much in the same way as peanut butter can be made from peanuts, the roasted cacao beans are ground into a paste known as cocoa liquor.

The liquor is mixed with the other ingredients, and ground together with heating (known as conching) to form liquid chocolate.

Fat crystals

The fluidity of the cocoa liquor comes from the fats released when the beans are ground. These fat molecules are known as triglycerides, and they resemble the letter Y with three long zigzagging arms connected to a central junction. The triglyceride arms can vary, but they tend to be a mixture of saturated and unsaturated fatty acids.



An example of a typical chocolate triglyceride with saturated and unsaturated fatty acids.

When the melted chocolate cools, these triglyceride fats assemble into highly ordered structures that are crystals at the molecular scale. Depending on how well the temperature is controlled, the fats can take on one of six different crystal structures. These different crystal forms are called polymorphs.

Control your temper

The most desirable crystal form gives chocolate a smooth, glossy appearance, a clean snap and a melt-in-your-mouth texture. Achieving this requires careful temperature control from liquid to solid through a process known as "tempering".

Poorly controlled cooling of the melted chocolate results in other crystal forms, which tend to have a less pleasing look and mouth feel – often chalky or gritty. These less desirable forms can convert during storage. And as the underlying crystal structure of the fats changes, some of the triglycerides separate.

These separated fats collect at the surface as colourless crystals, giving the chocolate a white fat bloom. This is especially noticeable if the chocolate is poorly stored and goes through melting and re-solidification.

The ingredients can also affect fat bloom. Cheap chocolate tends to use less cocoa butter and more milk solids, which introduces more saturated fats. Saturated fats are also common in nuts, and can migrate from the nut to the chocolate surface. So a chocolate-covered hazelnut is more likely to show fat bloom than a nut-free version.

Sugar or fat crystals?

Sugar bloom is less common than fat bloom, although they can look very similar. It occurs when sugar crystals separate from the chocolate, particularly under humid storage conditions.

You can tell the difference with a simple test. Sugar bloom will dissolve in a little water, while fat bloom will repel water and will melt if you touch it for a while. Unfortunately chocolate bloom can't be reversed unless you completely melt the chocolate and recrystallise it at the correct temperature.

The easiest ways to avoid bloom on your Easter eggs is by choosing a brand with a high cocoa butter content, transporting and storing your eggs at a low temperature and humidity, and making sure you eat them before their best before date – assuming they last that long!

Nathan Kilah MRACI CChem is a senior lecturer in Chemistry at the University of Tasmania. Republished from *The Conversation* (https://theconversation.com/whats-the-white-stuff-on-my-easter-chocolate-and-can-i-still-eat-it-181274).

When smoke is in the air

Smoke has long been used to flavour and preserve foods, and products with smoky characters – meat, seafood, cheese, spices, nuts and Scotch whisky – are still enjoyed today.

Similar characteristics in wine are not always pleasant. "Smoky" and "spicy" traits, among others, end up in wine when wines are stored in oak barrels for periods of time. These smoky traits are due to volatile phenols (VPs), which are lignin pyrolysis products extracted from toasted or charred oak. Oak sensory traits are desirable and generally improve the quality of wine. But "smoke taint", caused by bushfire (wildfire) smoke in the vicinity of vineyards, has a catastrophic effect on fruit and wine quality, and results in hundreds of million dollars in lost revenue for the Australian wine industry. This is now a significant global issue. With a changing climate, the incidence of bushfires is increasing, not only in hot and dry winegrowing regions of Australia but also in the US, Canada, Chile, France and South Africa.

We have worked on aspects of smoke taint for well over a decade and have an active Linkage Project on the topic. Some of that work is described here, but there is still more to be done.

The phenomena surrounding smoke taint in wine is complex – various VPs in smoke are absorbed by the grape and glycosylated at the phenolic hydroxyl group, leading to "bound" forms (Fig. 1) that can no longer be sensed by smell. This was first shown by a novel isotope tracer study whereby deuterated guaiacol was applied externally to grape bunches and leaves, with deuterated guaiacol glycosides subsequently being identified in extracts by high-performance liquid chromatography tandem mass spectrometry.

Further work involved the synthesis of deuterated phenols and their glycosides (including diglycosides containing glucose linked to another sugar) as standards, and analytical method development. Phenol glycosides are now routinely used as marker compounds for smoke taint diagnostics, along with the free VPs (to a lesser extent due to their presence in oak-matured wines). However, as with other bound flavour precursors in grapes, such as monoterpenoids and C_{13}-norisoprenoids, enzymatic activity during fermentation and the acidic pH of wine can release the VPs again, as can oral microflora upon tasting wine containing the glycosides. Thus, the presence of phenol glycosides in grapes – at the levels seen with smoke-tainted fruit – is problematic for producers, and an effective management or remediation strategy for smoke-tainted wine remains elusive.

Some recent and current work is aimed at developing remediation or prevention strategies – from protective coatings in the vineyard to winemaking practices – while still trying to understand VP uptake and glycosylation in the grape berry, and identifying potential new smoke taint marker compounds. With respect to the latter, volatile thiophenols have been proposed to act in concert with their VP analogues. As with other compounds containing a thiol group, the sensory detection

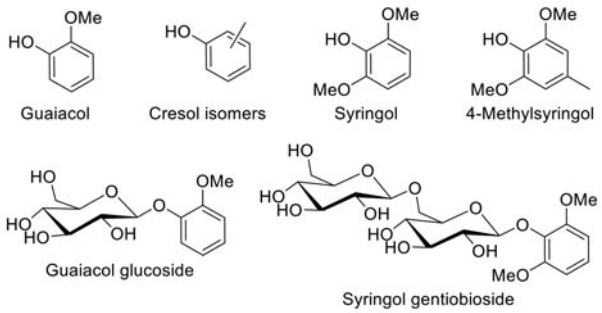


Fig. 1. Examples of volatile phenols and their glycosides. Guaiacol and syringol are described as smoke or medicinal, whereas cresols are more akin to leather, faecal and horse stable. Glycosylated forms are non-volatile and not perceived by smell.

thresholds of thiophenols (i.e. the concentration at which a proportion of the population could perceive a difference) are orders of magnitude lower than the VPs themselves, meaning that ultratrace quantities can have a significant sensory effect. The broad relevance of thiophenols to smoke taint is, however, an open question, as is their origin.

A promising amelioration strategy for tainted fruit involves the novel use of a spinning cone column for low-temperature distillation (also used for wine de-alcoholisation). This introduces a physical chemistry aspect, along with the synthetic and analytical tools mentioned earlier. Spinning cone column treatment of wine revealed only minor amounts of VPs found in the condensate (which contains ethanol and aroma compounds), so that they were concentrated in the treated wine – by up to 63% in the case of guaiacol at the highest strip rate. This was not the desired scenario because the smoke taint characters were exacerbated in the stripped wine, although future work could look at removing those VPs before reintroducing the ethanol and aroma-rich distillate fraction.

In contrast, treatment of juice revealed the opposite – VPs were distilled over and found in the condensate, probably as a result of a salting out effect due to the high concentration of sugar in the juice. This outcome is advantageous because many wine aromas are not present in juice but are formed during fermentation. In this case, the condensate (after passage through an ion exchange resin) was blended with the treated juice and fermented, with the resulting red wine having lower VP concentrations than the original juice (60% in the case of guaiacol and complete elimination of several other VPs). Curiously, syringol concentrations were increased in the resultant wine, which could be explained by hydrolysis of syringol gentiobioside (or other precursors) present in the juice.

More research is still required, including into the nature of the aglycones, to fully understand the chemical phenomena associated with smoke-tainted wine, but strong progress has been made since the issue first arose some 20 years ago.


Kerry Wilkinson FRACI CChem is Professor of Oenology at the University of Adelaide. **David Jeffery** FRACI CChem is Associate Professor in Wine Science at the University of Adelaide. References are available from the authors.

New year, new approach to work and life integration

Can you believe that in January you were relaxing on the beach, yet after returning from holidays you were quickly pressed for time with a truckload of work and energy-sappers coming at you from every direction? What has happened to your life? Is this how things will be until you fall over the line in a heap next December, only to start the whole cycle again next February?

We are generally reflective at the start of the year, and it can be hard to settle back into the work groove. Many of us are looking for different ways of working that give us greater control over our time. A new take on work–life balance, *work–life integration*, is a mindset that enables you to think differently about how you combine your work and personal life.

Contemporary thought about work–life balance suggests a sense of competition is created between work and life that in reality is often very difficult to achieve. Work–life balance captures the idea that work and personal lives are separate and that it's important to try to achieve equal time for each.

It's often associated with a juggling act that can be stressful and ultimately not very gratifying. When life incorporates home, family, community and personal health and wellbeing, endeavours to balance these with work can force unhealthy trade-offs.

By contrast, work–life integration is the idea that work and life are better when they intermingle. It's about seeing all your activities as a part of a whole rather than compartmentalising them. Rather than finding that elusive balance, or making trade-offs, work–life integration is about finding synergies.

This implies there are no boundaries in how you organise your work but, in reality, work–life integration cannot happen without your employer being onboard, especially in relation to flexibility. In part, work–life integration is driven by the blurring of personal and professional life as a result of technological advances that enable us to work from anywhere. This is often the case for chemists, although for those working in the lab it may require you to get more creative.

It's important to allow regular time for relaxation, exercise and appointments, and for organisations to encourage you to dovetail these with your work obligations. An option would be to get personal things out of the way early in the day and work later (or vice versa), or even intersperse them throughout the day. Everyone will have different needs according to their version of what is ideal for them. Too often, work commitments or "presenteeism" take precedence over your personal life.

You might also benefit from being better organised when planning your annual leave, especially regular short breaks to regenerate. There is a positive psychological effect from just knowing you have some leave booked in the calendar.

Some people feel as though their workload doesn't allow them enough time to take annual leave. Depending on which survey you read, up to 60% of Australian workers did not take all their annual leave days last year, while at the same time research indicates that most people do not think four weeks of paid annual leave is enough. We all know that not taking leave is ultimately damaging for wellbeing and productivity, so don't fall into that trap.

When everyone is overworked and not taking leave – including leaders in an organisation – and there is little opportunity to take advantage of flexible work options even if they exist, this is indicative of a poor culture. This can be a problem in competitive scientific environments with project deadlines, high workloads, constant grant applications and understaffing, and can often lead to stress, burnout and poor morale.

The main contributor to employee wellbeing, whether you are working in the office, the lab or remotely, is how well an organisation integrates wellbeing into work at the individual, team and organisational level. Hyper-competitive work environments where stress is built into the work can lead to a deviation from wellbeing even if people are getting sleep, exercise and eating well. Well-designed jobs and workplaces have always been, and will continue to be, key contributors to physical, mental and emotional wellbeing.

Compassion-centred workplaces respond effectively to burnout when it happens by focusing not only on the individual but on the work environment and operating systems. If this doesn't sound like your workplace, then looking for a new job is probably a good idea.

Dr Barbara Cosson and **Dr Janine Pickering** are co-founders of War on Wasted Talent (www.waronwastedtalent.com.au), a social enterprise providing career transition services for mature age professionals.

edwardolive/iStockphoto

A simple, smelly, dangerous liquid chemical

Some years ago, I was asked to suggest an organic solvent that could be used for the quantitative analysis of hydrocarbon mixtures based on the intensity of the C–H stretching vibrations in the infrared spectrum. This clearly called for a solvent with no C–H bonds, and moreover had no chlorine atoms, since the context was to prevent the depletion of stratospheric ozone under the Montreal Protocol. The obvious (to me) choice was carbon disulfide (CS_2), but I expected to be laughed out of court, so to speak, because although it's a very good solvent, it stinks, it's highly flammable, it's toxic, and it boils at the inconvenient temperature of 46°C. It took a while before I got the obvious response – thanks, but no thanks – and I think the reason for the delay was that most modern-day chemists are unaware of the existence of this simple chemical substance. As for "organic", I wasn't sure, but my trusty reference guide, the Chemical Rubber Company's *Handbook of chemistry and physics*, listed it among both the organic and the inorganic compounds; so you pays your money and you takes your choice.

Although it's very much a forgotten chemical, CS_2 (also known as carbon bisulfide) has played important roles in Australian agriculture and mining. Cuming Smith & Co. in Melbourne produced it by reaction of sulfur vapour with red-hot charcoal, and marketed it as a rabbit poison. As you can see from the relative molecular weights – 76 for CS_2 and 28 for nitrogen – carbon disulfide is much heavier than air, allowing the bunnies' living quarters to be filled with the toxic vapour. This was pumped into warrens with equipment like that shown in an advertisement placed by an equipment manufacturer in the *Australian Town and Country Journal* in 1917. Cuming Smith's agricultural chemist, F.E. England (an original member of the Australian Chemical Institute), said that there was no danger to the operator when it was used in the open.

That wasn't the case when it was used in an enclosed space to kill mice that had invaded grain stacks. In late 1947, three men pouring 40 gallons (200 L) of the liquid over 12 500 bags of wheat in a building in central Brisbane suffered severe poisoning. One, who had been working at the bottom of the stack while the others poured from the top, died. When rescuers opened the door to retrieve his body, there was an explosion that killed one of them and collapsed the wall of the building onto a nearby cottage, killing two occupants there.

Carbon disulfide is subject to nucleophilic attack in much the same way as its notorious sibling, carbon dioxide. Upon reaction with potassium or sodium alcoholates:

$$RO^- K^+ + S{=}C{=}S \rightarrow R{-}O{-}C(=S)S^- K^+$$

the products are dithiocarbonates known as xanthates. From the 1920s, xanthates were used as "collectors" in the froth flotation processes for separation of the ores of lead, copper or zinc from waste rock. The finely ground ore mixture was suspended in water containing dissolved xanthate and a frothing agent by bubbling air through the mixture, with the result that the valuable minerals were trapped in the froth, which could be skimmed off the top, leaving worthless material underneath, to be discarded.

Australian Town and Country Journal, 30 May 1917, p. 6

To return to the challenge, my inability to identify a suitable solvent having no C–H and no Cl brought about the relaxation of the latter criterion and we settled on perchlorethylene ($Cl_2C{=}CCl_2$), which worked well provided it was freed of hydrocarbon impurities. It's not an ozone-depleter and, although it is toxic, it is less so than CS_2, so it's manageable in a laboratory setting. "Perch", as it is known in the trade, is being phased out of industrial uses like dry-cleaning, but you can still catch a whiff of it if you patronise a dry-cleaner that has not yet gone "chlorine free".

Ian D. Rae FRACI CChem (idrae@unimelb.edu.au) is a veteran columnist, having begun his Letters in 1984. When he is not compiling columns, he writes on the history of chemistry and is an editor of *Historical Records of Australian Science*.

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1–4 July 2024, University of Sydney, Sydney, NSW

ORGANIC24
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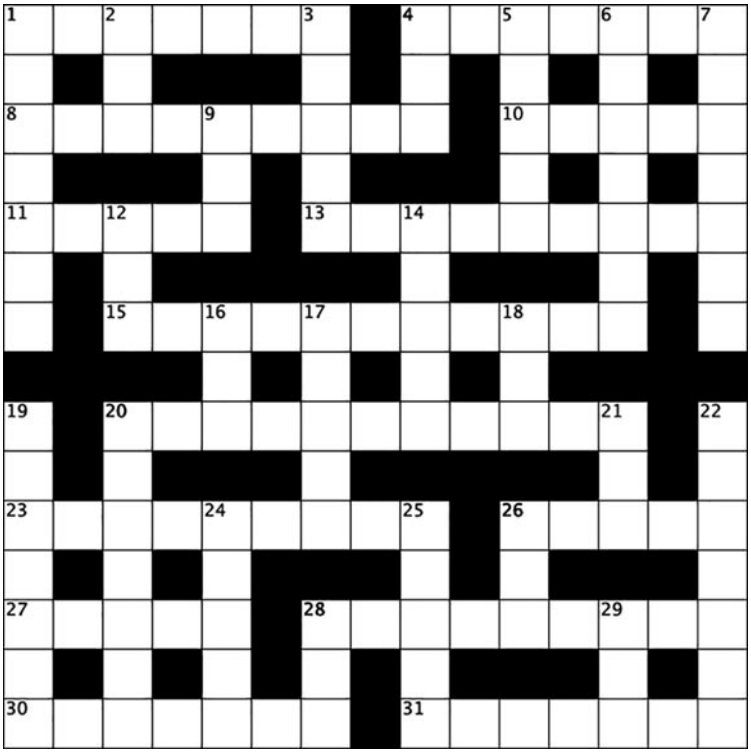

Across

1 26 Across reaction fuels it. (7)
4 26 Across got wind of ceremony held in the dark. (7)
8 26 Across soup's unavoidable outcome is sensed. (9)
10 Bull looked at loud 26 Across. (5)
11 & 26 Across Mixture alien to any deprotonated solvent molecule. (5,5)
13 26 Across ruined dry ox-hide. (9)
15 26 Across or a cation they formed. (11)
20 26 Across, 83, 28 Across. (11)
23 26 Across an extra OU delivery. (9)
26 See 11 Across.
27 26 Across backed in a hard-coded imagery program adopted in crude oil research. (5)
28 26 Across and 6 dined. (9)
30 26 Across friend, friend! (7)
31 26 Across spilt teaspoonful losing neptunium dioxide. (7)

Down

1 Purple sulfur reaction displays more flexibility. (7)
2 Look! Oxygen collects waste. (3)
3 Chase away cryptocurrency. (5)
4 Formerly the tenth electron. (3)
5 Characterised by turning proton without end. (5)
6 Mined with I_2 to make a nitrogen analogue of a cyclic acid anhydride. (7)
7 Fundamental feature of the place where one feels comfortable. (7)
9 Three and a bit made out dessert. (3)
12 Perform 89 over 6. (3)
14 The media zoo held there was $=N^+=N^-$ attached to a carbon atom. (5)
16 Three 7 Downs form a legal entity. (3)
17 About three 7 Downs. (5)
18 Doctors part of a hard-coded imagery program adopted in crude oil research. (3)
19 Four 7 Downs of fruit. (7)
20 Ligand 8 follows morbid map. (7)
21 Statement of intention to bid for inclusion in a hard-coded imagery program adopted in crude oil research. (1.1.1.)
22 Ring car points. (7)
24 Zone over 7 Down ring. (5)
25 Brings home and cleans up. (5)
26 Fuss over something found in a hard-coded imagery program adopted in crude oil research. (3)
28 Hot lead. Clue loses first letter. (3)
29 Yes! It's found in a hard-coded program adopted in crude oil research. (3)

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