Chemistry in New Zealand

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Rechargeable aluminium-ion batteries

A safer and cheaper alternative to lithium-ion batteries

- Mātauranga Māori and chemistry teaching: 'mauri is present in all matter'
- CRISPR: the best bet for a better world. Nobel prizewinning scientific discovery
- Sensory science: digitally unlocking the subconscious response

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Articles and features

Other columns

Comment from the President

Kia ora koutou

Spring greetings to everyone! This issue will find us in the latter part of the year hurtling towards Christmas once again. This will be the final column that I write as President and as such will be a reflective one but will also report on some fantastic achievements of our scientists and members.

With COVID dominating the scene since 2020, it has obviously been a very different experience from what one might have expected from an NZIC presidency.

During this time, it has been necessary to acclimatise to doing most things online, such as Council meetings and conferences. In doing so, it is likely that the usual social stimulation that people might get out of conferences or face to face meetings has been felt to be lost but on the other hand it has provided us through sheer necessity a different way for interacting where we are remote from each other and are unable to travel to be together for reasons of convenience, cost or other barriers. In this way we have had to be resilient and to carry out our research or business practices in a different way. The sliver lining of this is that when executed properly, these new ways of interacting have been far more inclusive and have expanded the contacts we have. A very good example is Commonwealth Chemistry where many nations spread across the globe are interacting via online means with face to face conferences to be organised for 2023 in Trinidad and Tobago.

As an Institute, I would like to think we have worked hard to keep members in the loop about Institute matters through online meetings and other communications. In particular I would like to thank the members of our Executive, Samantha (NZIC Administrator), Hamish (Honorary Treasurer), Sarah (Past President) and Joanne (Vice President) for their excellent efforts which combined have kept this Institute going through these difficult times. I also wish to acknowledge the assistance and time of our Council members for coming together in our meetings to offer excellent ideas and information. Despite these times, there have still been interesting and exciting changes occurring within the Institute, such as our new look webpage and our planned move to a wholly online and more interactive format for *Chemistry in New Zealand*. None of this would have been possible without the collective or individual efforts of our members.

Now with the borders fully open, it is hoped that we can once again see a flow of international students, workers and researchers into the country on a scale which will

hopefully come up to and even exceed the levels we enjoyed before COVID clamped down on the globe.

I would like to take this opportunity to convey congratulations from our Institute to Dame Professor Margaret Brimble who has achieved another major accolade, clearly demonstrating that New Zealand chemistry is at the top of its field. Margaret was awarded the prestigious Pedler Award for her excellence in research and innovation in the area of natural product synthesis, peptide chemistry and medicinal chemistry. In receiving his honour, she joins the ranks of an elite group of distinguished scientists which include Nobel Prize winners who have been awarded prizes by the UK-based Royal Society of Chemistry in the past.

As a final piece of business, Institute prizes for this year will be finalised at our Council meeting in late October. Once again, we have a talented group of applicants vying for these in addition to our new ACES prize.

I will soon start organising branch visits as President but these may occur later in the year.

The final major event of the year in the Institute's calendar will be the national NZIC conference to be hosted by the Auckland branch in November. This will be the first time we have had a major face to face conference and so it is hoped that many of you will take the opportunity to attend or to send your students or researchers to present seminars or posters. I look forward to seeing many of you there where I will chair my last AGM as President.

Noho ora mai

Michael Mucalo, NZIC President

NEWS

AUCKLAND

University of Auckland

EVENTS

■ In July, the director of the Science Scholars Programme at UoA, Dr Davide Mercadante, invited the Prime Minister's Chief Science Advisor, Dame Professor Juliet Gerrard to give a talk to the 150+ students in the 2022 programme. The programme consists of 1st - 3rd Year high achieving science undergraduates, many of whom are budding chemists!

STAFF SUCCESSES

■ Dr Jianyong Jin was announced as the winner of the Richard Robert Ernst Polymer Science Award for Young or Innovative Scientist at the 2022 POLY-CHAR conference. The award is given to an innovator who has made significant contributions towards solving pertinent societal problems, and was awarded specifically for Jianyong's work on living polymer networks.

■ Professors Jadranka Travas-Sejdic and David Barker were recipients of a University Research Excellence Medal, recognising their productive partnership in organic chemistry and polymer science.

■ Distinguished Professor Dame Margaret Brimble was awarded the Pedler Award by the Organic Division of the Royal Society of Chemistry, with the citation "For a large body of pioneering work spanning the fields of natural product synthesis, peptide chemistry, and medicinal chemistry".

STUDENT SUCCESSES

Rebekah Bradley (Forensic Science) won the Masters section of the 3 minute thesis competition at UoA with her talk titled, "Assessment of the MinION as a platform for forensic sequencing of mitochondrial DNA".

Chris Bainbridge with his award winning poster at the Dodd-Walls Symposium

■ Chris Bainbridge won the People's Choice award for Best Poster Presentation at the Dodd-Walls Centre Symposium from 5-7 July in Dunedin. His poster was entitled, "Creating a 4D polymer platform" and he is supervised by Dr Jianyong Jin and Professor Neil Broderick.

■ Patrick Imrie, a student of Dr Jianyong Jin, received the POLY-CHAR Award for the best poster presentation from students and young scientists at the POLY-CHAR 2022 conference. This conference was held as a digital event, with the next in-person POLY-CHAR conference being in Auckland in January 2023.

PhD COMPLETIONS

■ Honglei Ling successfully defended his PhD thesis entitled, "Synthesis of novel polymers of intrinsic microporosity for potential gas separation applications" supervised by Dr Jianyong Jin and Professor Duncan McGillivray. The project was funded by a National Science Challenge (NSC) programme.

■ Zainab Makinde successfully defended her PhD thesis, "Towards functional nanostructures using self-organising building blocks" supervised by Professors David Williams and Duncan McGillivray and Dr Laura Domigan (Chemical and Materials Engineering).

■ Brooke Kwai successfully defended her PhD thesis, "Structural and mechanistic investigation towards the regulation of *M.tb* isocitrate lyase" supervised by Dr Ivan Leung.

■ Tony Melton successfully defended his PhD thesis entitled, "Electroactive catalytic films for the removal of micropollutants from wastewater" supervised by Professor James Wright.

DEAN'S LIST

■ Two PhD students were placed on the Dean's List, in recognition of their outstanding theses:

Sunandita Ghosh: "Delivery of model bioactives by beta-lactoglobulin A based systems" (main supervisor - Duncan McGillivray).

Rory Devlin: "Inspired by nature: a biomimetic approach toward the total synthesis of Pterocellin A and Nudicaulins I and II" (main supervisor - Jon Sperry).

AUT

NEW FACES

■ Olivia Matich re-joins us to start her PhD after spending 6 months working as an intern at Mint Innovation (she enjoyed it so much, she was in two minds about coming back!). Olivia was awarded an AUT Vice Chancellor's Doctoral Scholarship and received top-up funding from the MacDiarmid Institute. She will be working with Dr Jack Chen on the development of synthetic enzymes for the degradation of plastics.

■ Ben Stackpole starts his Honours with Professor Nicola Brasch and Marc Malingin starts his Honours with Dr Jack Chen.

EVENTS

■ PhD students Jess Fredericksen and Anau Lautaha, along with Professor Nicola Brasch, attended the Dodd-Walls Symposium in Dunedin. Jess and Anau presented posters on their research and Jess won a poster award.

■ Dr Jack Chen gave a talk entitled, "Dynamic catalyst systems from the self-assembly of amphiphiles" at Supramol 2022 - XV Italian Conference on Supramolecular Chemistry, in Salerno, Italy.

CONGRATULATIONS

■ Anau Lautaha was awarded a prestigious AUT doctoral scholarship and has started her PhD under the supervision of Professor Nicola Brasch. Her research will focus on elucidating the factors that determine the mechanism of photodecomposition for photoactive HNO donor compounds.

■ Dr Jack Chen, in work led by collaborators at the University of Auckland, has published an article entitled, "Simultaneous extraction, derivatisation and analysis of varietal thiols and their non-volatile precursors from beer" in the journal *LWT – Food Science and Technology*.

Jess Fredericksen and Anau Lautaha at the 2022 Dodd-Walls Symposium

Auckland Cancer Society Research Centre

The ACSRC had a successful funding round in the recently announced HRC projects, winning four out of five applications for a total of $4.800M. Each project builds on our core focus of medicinal chemistry and extends to developing translational opportunities for our research. The successful projects were:

"Hypoxia-selective delivery of DNA-PK inhibitors to tumours" - Michael Hay (PI), Lydia Liew, Cho Hong, Gib Bogle, Tet-Woo Lee, Kimiora Henare, Stephen Jamieson, Bill Wilson and Way Wong. This project seeks to develop novel DNA-dependent protein kinase (DNA-PK) inhibitors which sensitise head and neck cancer cells and tumours to radiotherapy. Tumour selective targeting will be explored using hypoxia activated prodrugs of these DNA-PK inhibitors and tested in tumour xenografts to determine the advantage the prodrugs provide through sparing normal tissue and selectively killing tumour cells.

"Overcoming antibody-drug conjugate resistance in HER2+ve breast cancer" - Stephen Jamieson (PI), Euphemia Leung, Barbara Lipert, Tet-Woo Lee, Moana Tercel and Kimiora Henare. Antibody-drug conjugates (ADCs), where potent cytotoxins are linked to antibodies for selective delivery to tumours, are approved for the treatment of HER2 positive breast cancer. However, their use is limited by drug resistance. In this project, CRISPR/Cas9 functional genomics screens will be used to uncover novel genes that are implicated in resistance to different HER2-targeting ADCs (T-DM1, T-DXd, SYD985). New understanding of therapeutic resistance to these ADCs will identify potential combination therapy strategies to overcome ADC resistance and improve the clinical effectiveness of these agents.

"Targeted immune stimulants to hypersensitize lung cancer to checkpoint blockade" - Adam Patterson (PI), Jeff Smaill, Ian Hermans, Victoria Jackson-Patel, Alex Mowday and George Laking. Immunotherapy has emerged as an important new treatment modality, with new drugs becoming available that have been shown to induce remarkably durable responses in a proportion of patients with advanced disease. However, responders still remain in the minority and it is becoming increasingly clear effective immunotherapy requires a 'hot' inflamed tumour status. The group has developed a prototype tumour targeted immunostimulator that converts 'cold' cancers into responsive 'hot' cancers using a prodrug technology. The project will develop and characterise this novel class of immune agonists and identify a lead candidate for clinical evaluation in New Zealand.

"Critical evaluation of a tumour-targeted cancer therapy for clinical development" - Jeff Smaill (PI), Adam Patterson, Alex Mowday, Victoria Jackson-Patel and Peter Fong. Systemic administration of selective FGFR inhibitors is associated with dose-limiting toxicities derived from on-target inhibition of FGFR in normal tissues, requiring dose interruptions and reductions. Consequently, these toxicities compromise efficacy in the majority of cancer patients. To avoid systemic toxicities we have designed SN38180, a quaternary ammonium salt hypoxia-activated prodrug of a pyrido[2,3-*d*]pyrimidin-7(8H)-one acrylamide-based covalent pan-FGFR inhibitor that targets cysteine 488 in the p-loop of FGFR1-4 through a Michael addition reaction. We will critically evaluate SN38180 in preclinical models of cancer and demonstrate the promise of our approach to improve the treatment outcomes for cancer patients with FGFR-dependent disease.

In other news, Dr Andrew M. Thompson recently published a perspective in the *Journal of Medicinal Chemistry* (the leading international journal in this field) entitled, "Tuberculosis drug discovery: challenges and new horizons" (Fernandes, G.F.S.; Thompson, A.M.; Castagnolo, D.; Denny, W.A.; Dos Santos, J.L. *J. Med. Chem.* **2022**, *65*, 7489-7531).

Dr Andrew Thompson

This review has a major emphasis on profiling the more than 60 new compounds published in the last six years that demonstrate good efficacy in animal models and are therefore potential lead candidates for drug development. It also highlights the main challenges and strategies for discovering new tuberculosis (TB) drugs and details the current global pipeline of drug candidates in clinical studies.

To quote from one independent reviewer, "The authors have comprehensively addressed the contemporary issues facing medicinal chemists working on TB therapeutics, including a short history of the disease, a summary of current treatment modalities, a detailed discussion of compounds in various stages of clinical trials, and a tour de force overview of new approaches to TB drug discovery.

"The latter is organized by targets (when they are known) and accompanied by clear and useful pictorial summaries of some very complex drug discovery stories. They conclude with thoughtful, in-depth summaries of the state of the field."

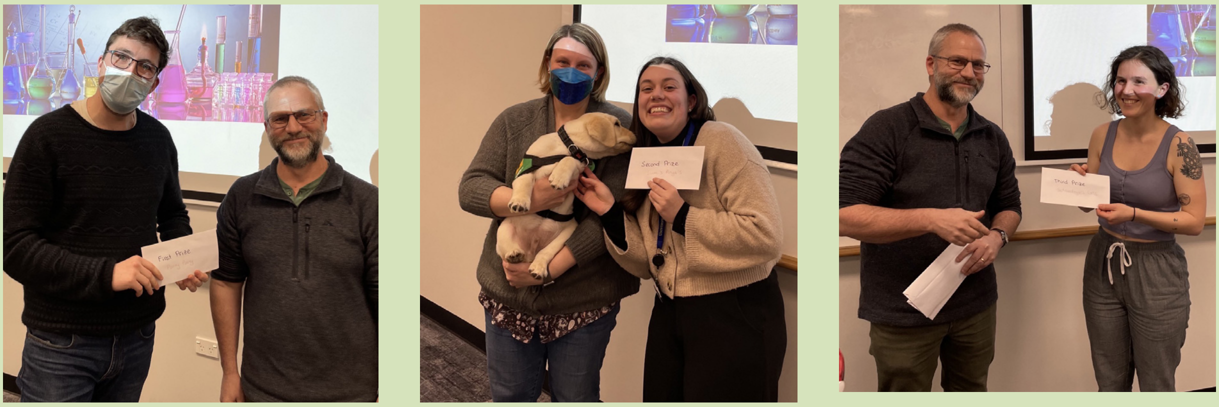
Dr Thompson began his career at the ACSRC in 1991, working in partnership with Pfizer initially on kinase inhibitors for cancer and later DNA gyrase inhibitors as potential antibacterial agents.

From 2005-2016, his research focussed on developing new drugs for tuberculosis and neglected tropical diseases, through collaborations with the Global Alliance for TB Drug Development and the Drugs for Neglected Diseases initiative (DNDi).

As part of this work, he designed and synthesised DNDI-0690, a first-in-class drug candidate for visceral leishmaniasis, which has recently completed phase I clinical trials and is expected to proceed to phase II proof-of-concept studies in patients. He is now working on several new tuberculosis drug discovery projects with both local and international investigators.

OTAGO

In August the Otago branch of the NZIC hosted its (semi) annual quiz night. The event was a big success, with the entry list filling up very quickly. Thanks to organiser Andrea Vernall, the question writers and quiz master Dr Dave McMorran for a fun



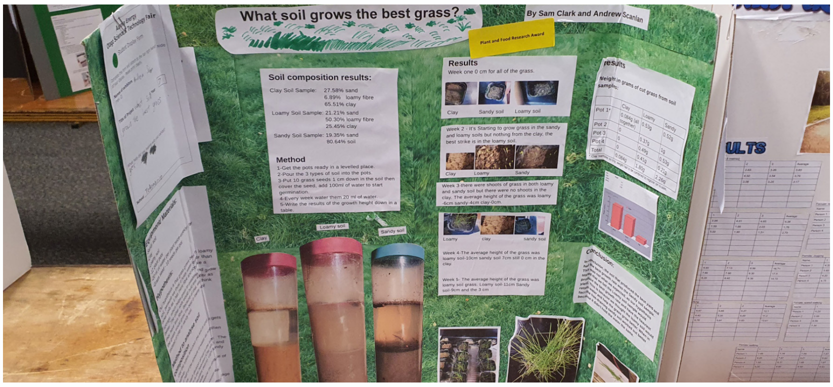
Otago NZIC branch quiz winners, pictured with quiz master Dave McMorran. Left to right: Ciaran Ward of Parity Party, Selena Gilmer (and Lumi) of Lumi's angels and Brie Nally of Schrodinger's Cats.

evening. First place went to Parity Party, second place to Lumi's Angels, third place to Schrodinger's Cats and the best team name was (Ele)mental breakdown.

■ A great array of over 200 posters were assembled at the Aurora Energy Otago Science and Technology Fair at the Otago Museum in Dunedin during the week of 15 August. These colourfully described the results from research projects run by Year 7 to Year 12 students. These were read and judged by people from various university departments, CRIs and other learned institutions. Allan Gamble and Courtney Ennis were judges for NZIC.

■ For Plant & Food Research, Kate Calhoun (Clyde) and Nigel Perry (Dunedin) awarded prizes to eight posters on topics in our field, including natural pigments and soils promoting grass growth.

Just two of the many excellent chemistry-themed entries at the Aurora Energy Otago Science and Technology Fair at the Otago Museum



The Department of Chemistry has a new four-legged thing hanging around for a year.

Introducing 'Lumi', who is a Mobility Assistance Dogs Trust Learner puppy. Lumi will be accompanying Andrea Vernall to lectures and first up he has 400-level, so Lumi is starting with the hard stuff.

University of Otago, Department of Chemistry

■ The Chatham Islands Festival of Science was held in Rēkohu Chatham Islands from 16-21 August. In this event, organised by David Johnston of Massey University, science was celebrated on the island in many events. Public (and pub!) talks were given, along with science open days at Te One Science House and Kōpinga Marae, a schools program, star gazing and the exhibition of Otago Museum's Far from Frozen exhibit at Chatham Islands Museum.

■ Anna Garden from Otago Chemistry/MacDiarmid Institute for Advanced Materials and Nanotechnology and Andy Wang from Auckland Chemistry/Dodd-Walls Centre for Photonic and Quantum Technologies were privileged to take part, alongside colleagues from the Otago Museum, Otago Department of Physics and many others. Thanks to the organisers and the locals and we hope to be back next year!

■ Ian Liddle and China Payne from the group of Andrea Vernall entered the Division of Science 3-minute thesis competition, with China Payne winning the Division of Sciences heat and going on to compete in the university finals.

Anna Garden explaining the properties of nanoscale zinc oxide in sunscreen at Hotel Chathams.

Students from Kaingaroa School, Chatham Islands, watching their crystal gardens grow

Students from Kaingaroa School, Chatham Islands learning about polymers with Anna Garden, Andy Wang and Toni Hoeta (Otago Museum).

■ CANTERBURY

University of Canterbury

PhD SUCCESSFULLY DEFENDED

Congratulations to Joshua Samaila, who successfully defended his doctoral thesis on 23 June.

Josh's thesis is entitled, "Approaches to synthesis of photoactivated cytotoxins" and he was supervised by Richard Hartshorn and Jan Wikaira.

Well done Josh, and good luck with your future endeavours! Details of Dr Samaila's thesis can be found here: https://ir.canterbury.ac.nz/handle/10092/104159

MANAWATU

PhD completions

Congratulations to the following people who successfully defended their PhDs:

- Sam Brooke: "The defect modes of MoS_2: indirect double resonance Raman spectroscopy in transition metal dichalcogenides" supervised by Professor Mark Waterland, Professor Richard Haverkamp and Associate Professor Geoff Waterhouse.

- Arka Gupta: "Discovery of novel plant based compounds to address the drug resistance problem in nematode infested ruminants" supervised by Associate Professor Dave Harding, Dr Preet Singh, Associate Professor Catherine Whitby, Dr Nadia Kondile and Professor Emeritus Bill Pomroy.

- Nimisha Mohandas: "Polysaccharide-DNA strings for single molecular polysaccharide studies" supervised by Professor Bill Williams and Professor Emeritus Geoff Jameson.

- Sashikumar Ramamirtham: "Structure-rheology relationships of protein-polysaccharide complexes at oil/water interfaces" supervised by Professor Bill Williams, Associate Professor Catherine Whitby, Dr Davoud Zare and Dr Mike Weeks.

STAFF NEWS

- Associate Professor Catherine Whitby delivered an online seminar on "Protein adsorption at the oil-water interface: effect of protein self-association" at the 17th Conference of the International Association of Colloid and Interface Scientists, 27 – 30 June.

- Associate Professor Catherine Whitby also delivered a presentation on soft material research into reconfigurable materials at the Sydney Nano-MacDiarmid CoRE workshop on 29 June.

Tauranga Girls' College, first place winners at the 2022 NZIC Analytical Chemistry Competition with competition sponsors and their teacher. From left: Bill Henderson (NZIC Waikato Branch), Sarah Cummings, Judy Shin, Helen Guo, Kell Crowther, Treena Blythe (teacher, back) and Rebecca Fitzgerald (Hill Laboratories).

Left to right: Megan Grainger, Simon Winship, Amber Bell, Erin Steed and Anya Noble attending the poster session at the Apiculture conference.

WAIKATO

NZIC Analytical Chemistry Competition 2022

This annual event was held on 28 June. Twenty-four teams of students from nineteen schools across the Waikato/Bay of Plenty region sent teams of four students to the university for the day to carry out the analysis for this year's competition.

"The task was to analyse the individual levels of barium and chloride ions in a sample of barium chloride and to use these values to determine how many water molecules were associated with each barium chloride molecule. One pair from each group of four analysed their samples to determine the barium ion content, while the other half of the team determined the chloride ion level. Although this was quite a challenging task in the time available, it was close between the top few teams," said competition judge and key organiser, Michèle Prinsep.

The competition allowed enthusiastic Year 13 chemists to spend a day in the university laboratories working on an experiment that would be beyond the resources of their schools. Although competition was intense, the main emphasis was on enjoying the experience of working in a chemistry laboratory at the university and meeting students from other schools. The winning team received

$280 and a trophy, with prize money also awarded to all other place-getters thanks to the generosity of the sponsors.

The day involved many of the Chemistry Department staff in setting up the competition and supervising the labs. Bryant Hall and Student Village provided excellent lunches, sponsored by the Waikato Branch of the NZIC. Hill Laboratories and the Waikato Branch of the NZIC generously donated the prizes.

NZIC ANALYTICAL CHEMISTRY COMPETITION RESULTS

1st Prize: Tauranga Girls' College

2nd Prize: St Peter's School 2
(Connor Delany, Masha Gavrilova, Paige Hughes, Bogie Jutanopparat)

3rd Prize: Hillcrest High School
(Alycia Begbie, Annie Li, Grace Ma, Freddy Wu)

4th Prize: Mount Maunganui College
(Anna Brock, Will Fraser, Benjamin Lindsey, Sam Petersen)

5th Prize: St John's College
(Flynn Beetham, Min Ki Hong, Alistair Sequiera, Marllone Villegas)

University of Waikato

■ Congratulations to Simeon Atiga who has completed his PhD thesis with Bill Henderson on new metal complexes of some thiosalicylate analogues.

■ Congratulations also to Humair Siddiqui Ahmed on completing a PhD in Engineering (supervised by Michael Mucalo) on the use of cattle bone and indigenous fibre-sourced char for preparing hydroxyapatite-carbon reinforced composites of biomedical value.

■ Daniel Reason has submitted his PhD thesis entitled, "Process optimization for the manufacture of medicinal cannabis products" supervised by Megan Grainger and Joseph Lane.

■ Megan Grainger and students Amber Bell and Simon Winship attended the Third New Zealand Honey Bee Research Symposium and Apiculture Conference held at Te Pae, Christchurch (29 June -1 July). Amber (supervised by Megan Grainger) presented results from her completed MSc research at the symposium. Her presentation, "An investigation of low diastase activity in mānuka honey" detailed how the loss of diastase in mānuka honey occurs faster compared to other honeys due to compounds naturally occuring in mānuka nectar. This has implications because diastase is used as a quality control parameter when exporting honey. Her talk was awarded second place in the student presentation competition.

■ Anya Noble (co-supervised by Megan Grainger) presented her PhD research, "Bacteria on the mānuka (Leptospermum scoparium) leaf surface: a potential driving factor of mānuka honey quality?" Her research has discovered a unique leaf surface microbiome on mānuka leaves. Amber and Anya also both presented posters on their research at the Apiculture conference.

Students participating in the high school titration competition and quiz.

■ WELLINGTON

The NZIC Wellington Branch Annual High School Quiz and Titration Competition was held on 29 July at the School of Chemical and Physical Sciences (SCPS) at VUW. It was great to be able to run this event after two years of disruption by COVID-19. The titration competition attracted around 15 keen and enthusiastic Year 12 students who carried out an indirect titration to determine the amount of ascorbic acid in a Berocca tablet. The students developed some great skills for their titration assessment. Well done to Wellington College for taking our first, second and third prizes – a huge success!

That evening, we had around 84 chemistry students making up 18 teams in the NZIC Quiz. The quiz was hosted by Finlay Burke and Courtney Davy. It started off with some fun and exciting chemistry demonstrations, followed by eight rounds of quiz questions, and lots of laughter and excitement from the students.

There was great competition between the teams and the winners for the night were:

- **First Place:** The Dysfunctional Group (Wellington College)
- **Second Place:** Bond – Covalent Bond (Wellington College)
- **Third Place:** All the Good Names Argon (Newlands College)

The Best Name award went to 'Got to keep ion us' from St Bernards College.

The students also had to design a new and creative element and the prize went to 'Quarantinium', inspired by the COVID-19 pandemic – well done to St Orans College on their brilliant idea! The students walked away with some awesome prizes.

Students participating in the high school titration competition and quiz.

VUW

- VUW spin-out company Inhibit Coatings was one of four winners of the Australia New Zealand Leadership Forum Trans-Tasman Innovation and Growth Award. Eldon Tate and Emma Wrigglesworth accepted the award on behalf of Inhibit Coatings from the Australian and New Zealand Prime Ministers Anthony Albanese and Jacinda Arden at an awards dinner in Sydney in July.

Eldon Tate and Emma Wrigglesworth with Australian and New Zealand Prime Ministers Anthony Albanese and Jacinda Arden.

- Another VUW start-up, TasmanIon (CEO: Shalini Divya – see article next page) has been nominated for a 2022 Earthshot Prize. There are five prizes, valued at £1,000,000 ($1,922,400 NZD), awarded by The Royal Foundation of the Duke and Duchess of Cambridge to projects that highlight human ingenuity, drive change and inspire collective action. We wish TasmanIon well in this prestigious competition.

- Martyn Coles gave his (belated) inaugural professorial lecture entitled, "The periodic table is my molecular lego" at the VUW Hunter Council Chambers on 14 June, well attended by VUW students, staff and leadership, members of the public and past colleagues. Martyn gave a fantastic synopsis of his world leading research involving a majority of elements in the periodic table and interesting and enjoyable anecdotes and reminiscences.

- On 29 July we were delighted to welcome Dr Ziyun Wang who visited SCPS from the University of Auckland to present a seminar on "Rational catalyst design for CO2 electrochemical reduction" and meet colleagues.

- SCPS has reinstated research colloquia for undergraduate students showcasing the research being undertaken in the School. Members of staff, both physics and chemistry, present short descriptions of their research area.

- At the August colloquium, chemists Kim McKelvey and Justin Hodgkiss spoke about their research on electrochemistry and solar energy to a rapt audience, alongside physics colleague Uli Zuelicke who described research in condensed matter physics.

Rechargeable aluminium-ion batteries

SHALINI DIVYA

TasmanIon Limited, Wellington (email: shalini@tasmanion.com)

Keywords: *aluminium-ion battery, cathodes, electrolyte, activated carbon, molybdenum dichalcogenides*

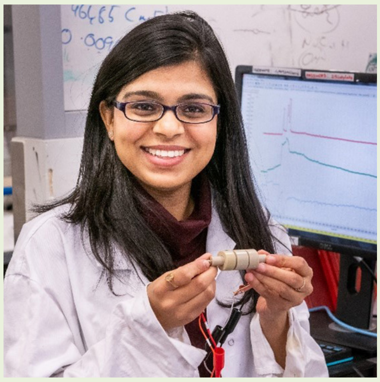
Introduction

Many steps have been taken to switch to renewable energy sources from non-renewables to combat climate change. By installing solar panels on rooftops, consumers can power their houses by trapping solar energy. The growing population is responsible for an increase in energy demands and the share of new renewable energy sources has also increased, with a sharp increase from 2005 to 2016. However, solar and wind energies have variable output. The sun doesn't always shine, and the wind doesn't always blow. Variability in solar and wind over the day leads to the requirement for large-scale energy storage devices. Batteries maximise the ability to use the electricity generated by renewable energy sources. When demand exceeds supply, the grid can use the stored energy and distribute it.

Aluminium-ion batteries (AIBs) are a safer and cheaper alternative to lithium-ion batteries (LIBs) due to the abundant and ethical supply of raw materials. Researchers at Victoria University of Wellington have tested various cathode materials with varied morphology to find a suitable cathode material for AIBs that use aluminium metal as the anode. This article summarises the work done by researchers who aim to broaden the technical development pathway and commercialise the technology.

■ Dr Divya is the co-founder and CEO of TasmanIon. She received her PhD in chemistry in 2020 from Victoria University of Wellington. Her PhD was based on non-aqueous aluminium-ion batteries (AIBs) under the supervision of Professor Thomas Nann. Her discoveries in novel cathode materials for AIBs are a core part of TasmanIon's intellectual property.

Dr Divya completed her BSc (Hons) in chemistry at Delhi University and her MSc in chemistry at Birla Institute of Technology, India. She won a SfTI (Science for Technological Innovation) grant worth $200,000 from MBIE in September 2021 and KiwiNet's



Breakthrough Innovator Award during the Research and Commercialisation Awards in November 2021. Dr Divya's vision is to make TasmanIon's batteries the safest and the greenest in the world!

Battery terminology

Understanding a few terms that help evaluate performance is vital to understanding how batteries function.

Electrodes

In batteries, electrical energy is generated by converting chemical energy via redox reactions at the anode and cathode. As reactions at the anode usually occur at lower electrode potentials than at the cathode, the terms negative and positive electrode are used. The more negative electrode is called the anode, whereas the cathode is the more positive one.[1]

Battery capacity

Capacity is the amount of charge or energy stored in a battery. The fundamental unit of battery capacity is the coulomb (C), though Ampere-hours (Ah) is more commonly used. Theoretical capacity (the ideal capacity a battery can store) is calculated with the help of chemical reactions that take place inside the cell. Using the Faraday constant, F (F = 96,484.56 C mol^{-1}), the theoretical capacity of a battery can be determined using Eq. 1:

$$\frac{n \times F}{3600 \times M} = \text{Capacity (Ah)} \qquad \textit{(Eq. 1)}$$

where:
n = number of electrons participating in the electrochemical reaction
F = Faraday constant
M = molar mass

Specific capacity is the capacity stored in a material per unit mass. The most commonly used unit for specific capacity is mAh g^{-1}.

Battery potential or voltage

The point (usually in the middle of a discharge curve) where voltage stays constant for the longest period forming a plateau, is the nominal cell voltage. Various factors are responsible for determining a cell's voltage, such as electrolyte stability and polarisa-

Table 1. Characteristics of commonly used rechargeable batteries					
	In market since	Energy density (Wh kg^{-1})	Nominal Voltage (V)	Applications	Limitations
Lead-acid	1881	30-50	2.0	Backup power supplies for telephone centres, grid energy storage, uninterrupted power supply (UPS)	Environmental hazards, risk of thermal runaway, transportation restrictions
Nickel-Cadmium	1960	40-80	1.2	Portable electronics, toys, cordless telephones	Environmental hazard, low energy density, high self-discharge, explosive
Nickel metal hydride (NiMH)	1990	60-120	1.2	Consumer electronics, electric vehicles, hybrid cars	Expensive, high self-discharge, high maintenance
Lithium-ion: $LiCoO_2$	1991	150-190	3.6	Smartphones, laptops, tablets, digital cameras, hybrid vehicles, electric motorcycles, scooters, bicycles, personal transporters	Safety hazard, risk of thermal runaway, transport restrictions, environmental hazard, dendrite formation
$LiMn_2O_4$	1996	100-135	3.8		
$LiFePO_4$	1999	90-120	3.3		
Lithium nickel manganese cobalt oxide (LiNMC)	2008	190-210	3.6		

tion of the battery (displacement of electrode potential from the equilibrium value). Going beyond the upper or lower cut-off voltages might lead to side reactions resulting in electrolyte decomposition, causing an irreversible capacity loss. When a distinct discharge plateau is not observed, the intersection of the charging and discharging curves is called the average potential.

Energy density

The amount of energy stored in a battery per unit mass or volume is energy density. A high battery capacity or voltage or both are the prerequisites of a sound battery system. A simple way to determine the specific energy or energy density of a battery is to use Eq. 2, where the battery capacity is defined with respect to the cathode weight.

$$\text{Energy density (Wh kg}^{-1}\text{)} = \text{battery capacity (Ah kg}^{-1}\text{)} \times \text{battery voltage (V)} \quad \text{(Eq. 2)}$$

Coulombic efficiency (CE)

Coulombic efficiency of a battery is the ratio of the number of charges that enter during charge to the amount that can be extracted from the battery during discharge. A high CE above 95% is considered a standard value for commercial battery systems.

Sometimes, the charging and discharging rates also affect the battery capacity. If a high discharge current is applied (i.e., the battery is discharged quickly), its capacity decreases because the reactions inside a battery are not completed. Only a fraction of the total reactants is converted to the final product making the battery less efficient. Alternatively, if a battery is discharged using a low current, more energy can be extracted, increasing its capacity. A battery's specific capacity is typically higher with increasing temperature. However, intentionally elevating battery temperature is ineffective as this might decrease battery life.2-3

An ideal battery should be low-cost, charge and discharge indefinitely under a high or low current rate, have a long lifetime with high CE (>99%) and experience low-self discharge. While it isn't easy to fulfil all of these requirements, researchers are building new batteries that might achieve these objectives in their way.4–6 Every appliance that uses rechargeable batteries has its specifications. Portable electronic items need faster charging rates; therefore, LIBs are used extensively. On the other hand, nickel metal hydride (NiMH) and nickel-cadmium (Ni-Cad) batteries are more cost-effective than LIBs and widely used in making electric vehicles. Although a hybrid car that uses Ni-Cad or NiMH battery costs around $23,000, a Tesla that uses LIBs starts at $35,000.1 Table 1 describes the applications and limitations of batteries in the market.

Characteristics of an ideal cathode material

Prerequisites of an ideal cathode include:

- The discharge reaction should yield a high discharge voltage
- The material should be inexpensive, low in toxicity and chemically stable

- The structural changes during intercalation deintercalation should be minimal
- The active material should be able to intercalate the ions, preferably with a low molecular weight.

A perfect battery that is suitable for all applications does not exist. For example, a lead-acid battery works well for an automotive starter battery where it provides the required high-rate capability. However, its toxicity and low energy density would not be suitable for portable electronics.

Similarly, not all elements in the periodic table that may provide high energy density can be commercialised for everyday use. Fig. 1 displays the elements that can be used for designing new cathodes. Radioactive elements, heavy metals and inert gases should never find any long-term practical use in battery applications. Transition metals have variable valence states, which increase the number of electrons.

Some transition metals, such as vanadium (V) and cobalt (Co), are being used as cathode materials in LIBs despite their toxicity.[7–9] Carbon is one of the cheapest materials to store a large amount of energy.[10] This is one of the reasons why carbon-based materials are the premium choice in any energy storage device. Potassium and calcium-ion batteries have also been studied.[11]

The drive for using a battery technology based on Li metal as an anode was based on its "electropositivity" of -3.04 V versus the standard hydrogen electrode (Table 2), thus enabling high energy density.[11-12] LIBs rapidly found applications as power sources for watches, calculators or medical devices due to their high capacity and variable discharge rate. By 1972, the concept of electrochemical intercalation and its potential use was defined, although the information was not widespread.[13]

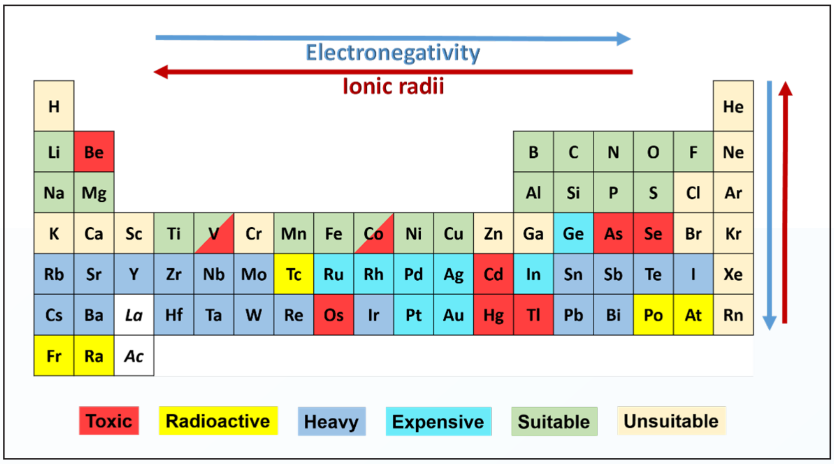


Fig 1. The periodic table suggests elements that can be used as battery materials. A few elements from this table have shown good electrochemical performance, such as molybdenum (Mo), tin (Sn), niobium (Nb) and tungsten (W).

LIBs are a popular battery choice for most applications. However, future battery demand will place increasing pressure on lithium and cobalt reserves and supply lines in the medium and long term. Moreover, the electrolyte used in LIBs is flammable - a safety issue that must be managed. Any mechanical damage to the cell might result in short circuits or thermal runaway reactions, sometimes leading to an explosion.

The high abundance and easy accessibility of aluminium resources enable AIBs to offer the opportunity to become an ideal alternative for energy storage systems. Since a multivalent ion insertion is feasible, higher energy densities can be achieved.[14] Non-aqueous AIBs use a non-flammable ionic liquid as their electrolyte, making them safer than LIBs in this regard. AIBs use aluminium metal as an anode, making it cost-effective, recyclable and environmentally friendly. Due to the three electrons in its valence shell that can easily participate in an electron transfer process, a multi-electron reaction is feasible, increasing its theoretical energy density (Table 2).

Aluminium-ion batteries

The idea to use Al in batteries was born in the late 1800s. Inventors like Joseph Richards in 1890, and James Sully, in 1897 worked on primary batteries using a carbon-aluminium electrode.[15-16] They aimed to provide an aluminium dry cell with a longer shelf life. These cells maintained a nearly constant electromotive force (EMF) on a closed circuit for several weeks. The negative electrode was

Table 2. Comparing battery parameters for various metal anodes

	Lithium	Sodium	Magnesium	Aluminium
Valence electrons	1	1	2	3
Theoretical specific capacity (mAh g^{-1})	3862	1166	2205	2980
Standard reduction potential (V)	-3.04	-2.71	-2.36	-1.68

externally exposed to air, and a mixture of potassium carbonate (K_2CO_3) and kerosene oil was used as the electrolyte. Another attempt was made to make commercially viable Al batteries in the 1950s. In 1951, Donald Sargent reported a voltaic cell especially adapted for use as a dry cell. The negative electrode consisted of Al and the electrolyte was made of a mixture of zinc oxide (ZnO) and sodium hydroxide (NaOH), with carbon acting as the positive electrode.[17] Both systems suffered from a layer of aluminium oxide (Al_2O_3), also known as "passivation", leading to very low energy densities and hence could not be commercialised.

Aluminium–air batteries produce electricity from the reaction of oxygen in the air with Al. The cathode is immersed in a water-based electrolyte (alkali metal salts) and forms hydrated Al_2O_3. Once the Al anode is consumed by its reaction with atmospheric oxygen at the cathode, the battery can no longer operate. However, the passivating oxide layer on the anode surface was still a matter of concern and was continuously deteriorating the battery performance.[18–20] The passivation caused a decrease in the electrode potential resulting in lower cell voltages than the expected theoretical value.

Since the standard electrode potential of Al^{3+}/Al at -1.68V is lower than H^+/H_2, the evolution of hydrogen gas occurs when Al foil reacts with aqueous acid or alkali solution. Thus, Al cannot undergo electrochemical stripping or deposition in an ordinary aqueous solution.[21]

Finally, in 2010, Paranthaman *et al.* made the first rechargeable AIB using a cathode composed of manganese (IV) oxide (Mn_2O_4) and an ionic liquid (IL) as the electrolyte, based on work by Jiang *et al.* and Peng *et al.*[22-23] The electrolyte was made of aluminium trichloride ($AlCl_3$) and 1-ethyl-3-methylimidazolium chloride (EMImCl), discovered by Gifford *et al.* in 1988[24], in a ratio of 2:1.

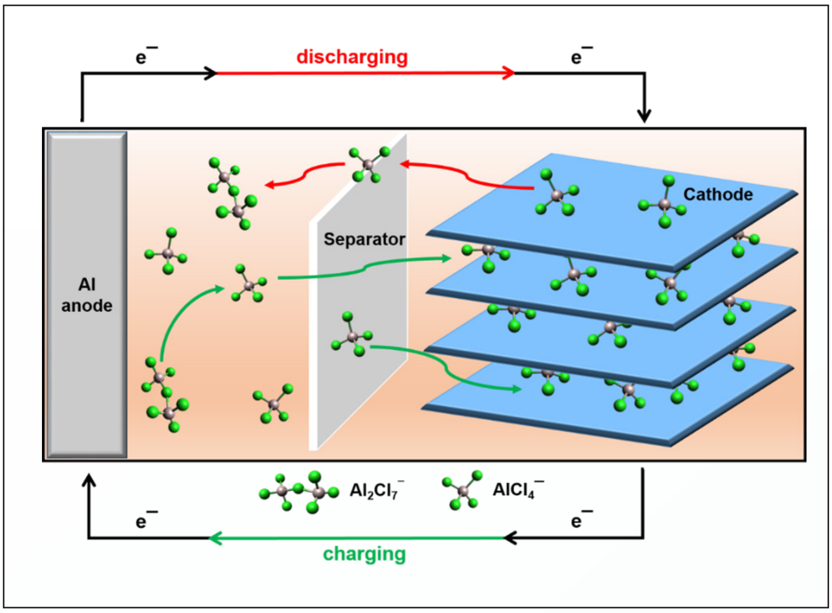


Fig 2. A schematic representation of a non-aqueous AIB. The aluminium metal foil acts as an anode. The cathode is typically a layered structure that would allow easier intercalation of ions. The separator (in white) ensures that the anode and cathode do not contact each other. The electrolyte contains the chloroaluminates from the AlCl3/EMImCl responsible for the cell reactions.

Reversible deposition and dissolution of Al occurred in non-aqueous electrolytes such as molten salts, NaCl-$AlCl_3$ or ILs (quaternary ammonium species) at room temperature with no passive oxide layer being formed on the Al anode.[25–27] The higher concentration of $AlCl_3$ makes the IL a Lewis acid, which prevents Al passivation. The stability of the ILs within the electrochemical window prevented side reactions and enabled the deposition of Al, which increased the cell voltages.[19] ILs consist of weakly coordinated complex ions, which are liquid below 100°C, or at room temperature.[28]

Another advantage of the ILs is their wide electrochemical window, ranging from 4.5 to 6.0 V. This makes them suitable for high-performance energy storage devices.[29] In addition, most ILs show high thermal stability, non-flammability, non-volatility, and zero vapour pressure compared to organic solvents.[30] Furthermore, they reach an electrical conductivity of 10 mS cm^{-1}, similar to the magnitude of most aqueous electrolytes.[31-32] Al deposition (during charge) and dissolution (during discharge) at the anode occur in a Lewis acidic IL containing $Al_2Cl_7^-$ shown in Eq. 3.[33] The equation is reversed during discharge. During charge:

$$4Al_2Cl_7^- + 3e^- \rightarrow Al + 7\,AlCl_4^- \quad \text{(Eq. 3)}$$

Al_2Cl_7 anions are formed when the molar ratio of $AlCl_3$ is higher than 0.5, and the IL becomes a Lewis acid. An excess of the cation results in an IL, a Lewis base, due to free halide ions shown in Eq. 4.[34]

$$AlCl_4^- \rightarrow Al_2Cl_7^- + Cl^- \quad \text{(Eq. 4)}$$

Using an $AlCl_3$/EMImCl electrolyte in AIBs was a breakthrough since most earlier inventions displayed low capacity and were not good enough for long-term practical use. EMImCl/$AlCl_3$ has been the most used electrolyte for non-aqueous AIBs. Fig. 2 is a schematic of an AIB using an IL (made of EMImCl/$AlCl_3$) electrolyte and 99% pure Al foil as anode and a graphite cathode.

We have tested cathodes from two families based on their type and structure. Carbon-based materials, such as graphite, a form of carbon with a layered hexagonal structure, have been commonly used as electrodes in various battery systems.[5,35–37] Its layered structure allows ion insertion, and it also has good thermal and electrical conductivity and a high electrical potential vs. Al/Al^{3+} of 2.1 V.[38]

In graphite-based batteries, chloroaluminate anions intercalate into the graphitic layers when the cells are charged and deintercalation occurs during discharge. Electroplating and dissolution of Al take place at the anode. Different forms of graphite have been used in AIBs. Yu *et al.* made an AIB using graphene nanoribbons on highly porous three-dimensional (3D) graphene foam as the cathode. Fluorinated graphite, kish graphite flakes, 3D graphitic-foam, graphene aerogels, and several other forms have been tested, which showed discharge capacities ranging from 60-250 mAh g^{-1}.[39-40] Several reports indicate that amorphous activated carbon (AC) with a large surface area exhibits excellent performance and capacity since high porosity provides many active sites.[41-42]

Our previous work tested various carbon-based materials as cathodes for non-aqueous AIBs.[43] Activated carbon derived from hair and hemp, Super-P carbon (a conductive additive used to improve electronic conductivity in a battery slurry) and fullerenes were investigated as potential cathodes. It was discovered that Al-hair batteries performed better than state-of-the-art Al-graphite batteries. The Al/hair battery recorded the highest specific capacity after 50 cycles at 103 mAh g^{-1} with a CE of ~90%.

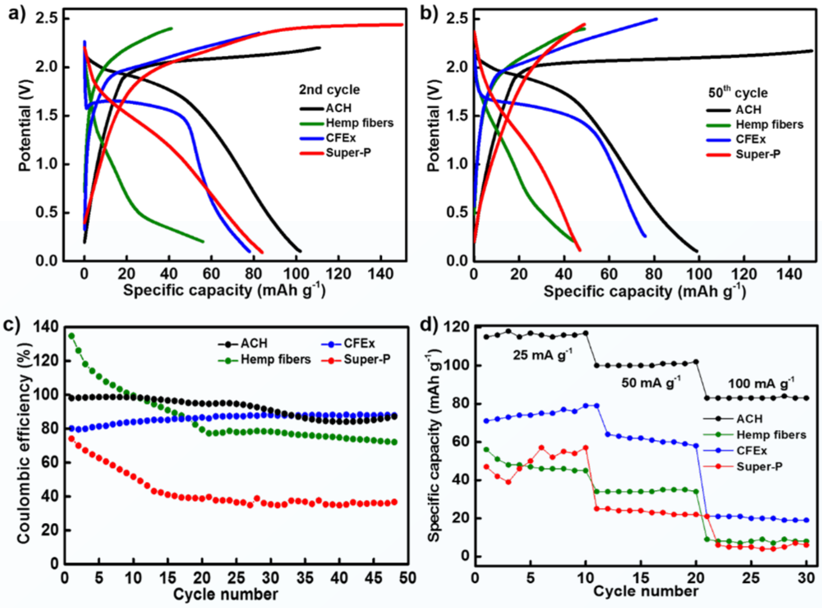


Fig 3. Specific capacities of activated carbon from human hair (ACH), hemp fibers, CFEx, and Super-P in their a) first and b) 50th cycle at a current rate of 50 mA g-1. c) Coulombic efficiencies (CEs) of cells at a current rate of 50 mA g-1. d) Galvanostatic charge/discharge profile of all cells at various current rates ranging from 25 mA g-1 to 100 mA g-1. Reproduced with permission from reference 43.

Fig. 3 illustrates the performance of the cathodes at different cycles. Fig. 3d shows the change in specific capacity at various current rates. We hypothesised that a dual mechanism was in place and both the intercalation and absorption of chloroaluminates occurred during the electron transfer.

Fullerenes, on the other hand, have a sponge-like structure. During cell charging, ions were absorbed on the surface of the buckyball and then desorbed during discharge. Also, the ions used the empty spaces between two fullerenes as intercalation sites. It was deduced that Super-P, a commonly used cathode additive, was not a suitable cathode material. It had an unstable structure that collapsed after a few charge/discharge cycles.

Fig. 4 illustrates the possible mechanisms followed by the different cathode materials. The excellent battery performance from the Al/hair system can be attributed to the material's porosity combined with high surface area and heteroatom doping effects resulting in surface-based non-faradaic electron transfer reactions. Furthermore, hair-based AIBs would prove to be cheaper than state-of-the-art LIBs.

Table 3 compiles the battery metrics of all the tested carbon-based cathode materials investigated in our previous work.

Table 3. Comparison of battery metrics of tested carbon-based cathodes

Active material	Specific capacity (mAh g^{-1})	Cell efficiency (%)	Cell voltage (V)
Human hair	102	97	1.9
Fullerene mix	79	85	1.7
Hemp fibers	49	75	1.8
Super-P	46	40	1.5

The second cathode material tested was two-dimensional (2D) transition metal dichalcogenides (TMDs). These materials offer tunable chemical and physical properties due to their various elemental compositions and crystallographic structures. In addition, they possess excellent electrochemical properties.[44] A 2D plane imparts a high surface area, which allows complete utilisation of all available sites in a cathode material similar to graphite.[45-46]

TMDs have gained enormous attention in recent years. MoS_2 has been previously reported in the literature as a cathode material, where Al^{3+} ions were inserted between the MoS_2 layers during cell discharge (Fig. 5). However, preliminary DFT results showed that the d-spacings of the layers would decrease significantly if cation intercalation occurred.

Our work hypothesised that anion intercalation of $AlCl_4^-$ would be more favorable than cation intercalation. The hypothesis was proved using analyses such as CV plots, charge/discharge curves, XPS and XRD data.[47] The batteries showed clear discharge voltage plateaus at 1.5 V for MoS_2 and $MoSe_2$ and 0.6 V for MoSSe. MoS_2 and $MoSe_2$ have similar crystal structures; interestingly, it was found that $MoSe_2$ performed better than MoS_2. $MoSe_2$ cells record a discharge capacity of 110 mAh g^{-1} with an average potential of around 1.9 V and 1.3 V during discharge. MoSSe exhibited a higher specific capacity over MoS_2 and $MoSe_2$ but the energy density was lower than $MoSe_2$ at a given current rate.

Despite having similar structures, $MoSe_2$ achieved higher capacity than MoS_2 and MoSSe (Fig. 6). XRD showed that MoSSe did not have a regular crystalline structure. Since it degraded rapidly after a few cycles, the material did not store energy reversibly, and the cells became inactive. Also, sulfur is more electronegative than selenium, and it might be

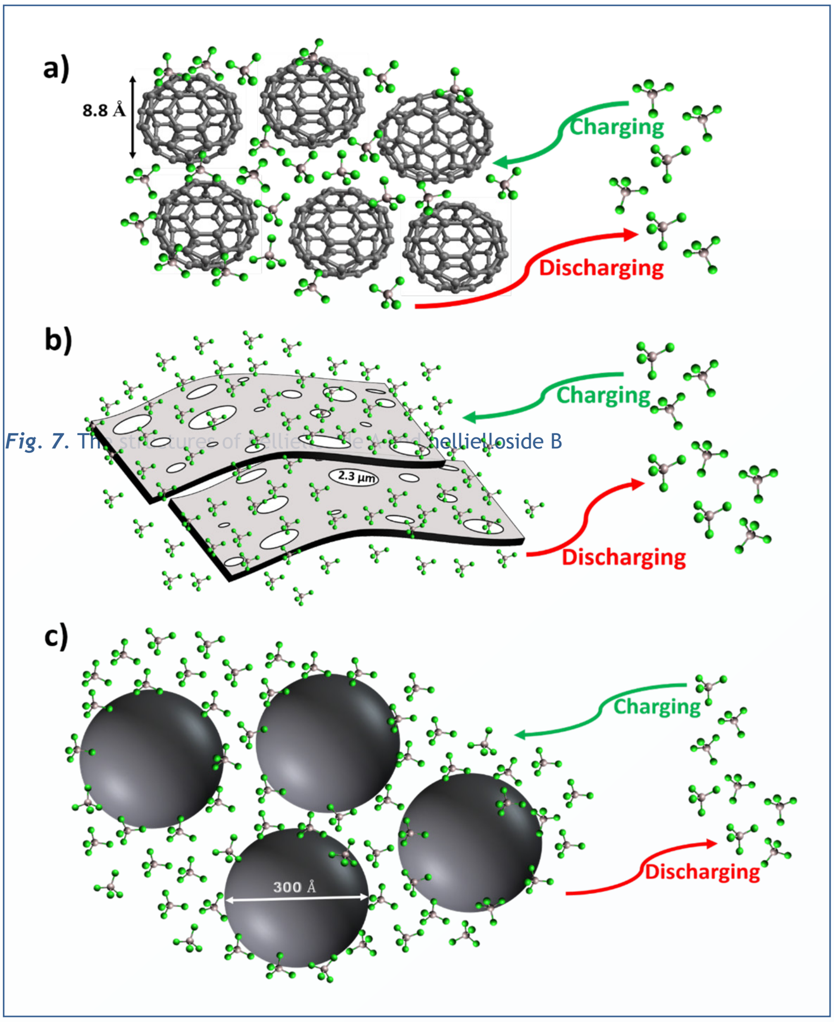


Fig 4. A suggested mechanism for an a) Al/CFEx cell, b) Al/hemp cell (hemp fibers have pore sizes as large as 2.0-2.5 mm, allowing the $AlCl_4^-$ to be absorbed onto their surface but agglomeration of these fibers after a few cycles reduced the number of active sites available for effective charge storage) and c) Al/Super-P cell (chloroaluminates intercalate into the very few graphitic planes in Super-P while at the same time a few anions adsorb onto its surface with further cycling leading to cathode pulverisation which results in capacity fading).

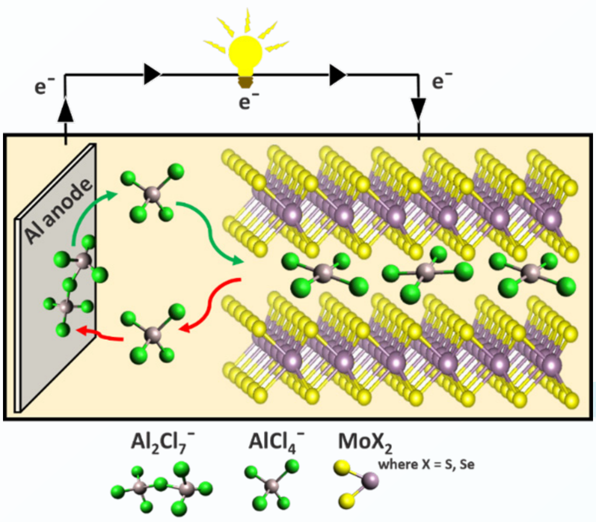


Fig 5. Schematic representation of an Al/MoX_2 battery. Chloroaluminates intercalate in between the layers during charge and discharge.

that the Al_xCl_y anions were distributed more evenly over the cathode surface, allowing better reversibility of electrochemical reactions. Although MoSSe displayed very high capacities (300 mAh g^{-1}) in its initial cycles, its overall energy density was much lower than MoS_2 and $MoSe_2$.

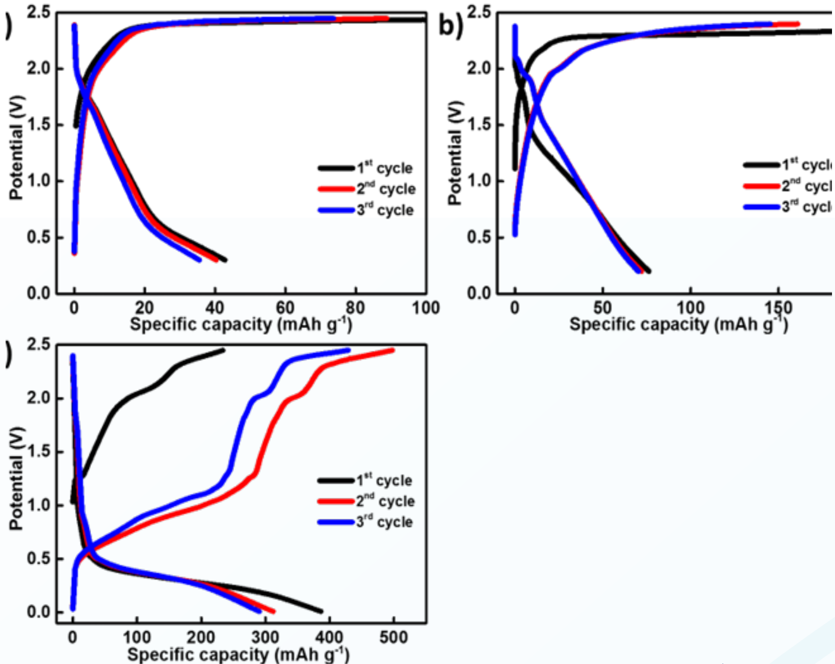


Fig 6. The first three charge/discharge cycles at a current rate of 40 mA g^{-1} for a) MoS_2, b) $MoSe_2$ and c) MoSSe cells at a current rate of 40 mA g^{-1}. Reproduced with permission from reference 47.

Commercial activity

The team at Victoria University of Wellington filed a provisional patent on an undisclosed cathode material in December 2019. The IP is licensed under a university spinout company, TasmanIon, which will commercialise AIBs soon.

Several companies are working on AIB chemistry at varying stages of commercialisation. Most companies use graphene as the cathode material in their AIBs. At Stanford, scientists (led by Professor Hongjie Dai) used graphene foam as cathode material and aluminium foil as the anode. The performance equated to 7,500 cycles (more than the 1,000 expected from a Li-ion battery).[38] Researchers demonstrated the properties of their newly developed batteries by drilling a hole in them while they were still working and the batteries did not explode or catch fire. The energy density sits at around 40 Wh kg^{-1}.

At Cornell University, scientists used a 3D-structured anode in the AIB with the typical ionic liquid as the electrolyte.[48] They created a 3D Al anode and graphite-based cathode with long cycle life. Using a porous design and graphite-based cathodes, the team has created a battery lasting up to 10,000 cycles without failure.

Researchers at Clemson University have designed an AIB with a graphene foam cathode. The team constructed batteries with aluminium anodes, pristine or modified few-layered graphene (FLG) cathodes and an $AlCl_3$/EMImCl electrolyte. The battery achieved a capacity of over 70 mAh g^{-1} for 1000 cycles, with a complete charge/discharge cycle taking less than three minutes. The energy density is approximately 200 Wh kg^{-1}.[49]

A lower cost per kg than competitors and a low cost of raw materials are needed for AIBs to enter the battery market. Due to minimal flammability risk and abundant and ethically mined materials, AIBs are safer and more sustainable than LIBs and commercialisation efforts in the field should be actively pursued.

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Article

Mātauranga Māori and chemistry teaching: 'mauri is present in all matter'

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Keywords: *mauri, life force, Mātauranga Māori, curriculum*

Introduction

When a new concept is introduced into chemistry teaching within New Zealand schools, it is important that professional chemists have the opportunity to review and comment upon the syllabus. Within the revised Chemistry and Biology Matrix for Curriculum Level 6 (Year 1 of NCEA), the following description is provided for one of the Big Ideas concerning attractive forces between particles:

"Mauri is present in all matter. All particles have their own mauri and presence as part of a larger whole, for example within a molecule, polymer, salt, or metal. When matter is broken into smaller particles each particle remains as part of the taiao, for example when a substance is burnt or dissolved the particles remain, with their own mauri."[1]

The following glossary is provided, where taiao is defined as "all conditions of the environment…", and in which mauri is defined as:

"The vital essence, life force of everything: be it a physical object, living thing or ecosystem. In Chemistry and Biology, mauri refers to the health and life-sustaining capacity of the taiao, on biological, physical and chemical levels."[2]

In this instance, a concept from Mātauranga Māori has been brought into a foundational science course. Its meaning thus needs to be made clear to students, parents and teachers alike, both those responsible for teaching this particular course, and for those who will teach courses later in high school and at universities that build upon this learning.

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He was responsible for setting up the postgraduate Wine Science programme in 2003. Paul is of Ngāi Tahu descent and is a Trustee on two blocks of forested land provided to the family under the 1906 SILNA Act. His research into family history, connected to his home marae at Arowhenua near Temuka, has been deposited with the Ngāi Tahu whakapapa unit.

In this article, a range of understandings of 'mauri' will be first presented, as expressed in records of oral traditions and in the writings of experts who have sought to explain its meaning within the Māori world view. This will be followed by a discussion of the compatibility of these meanings with modern chemistry, including past examples of life force concepts. Finally, questions are raised about how this Big Idea within NCEA has developed, including feedback on the proposals received to date.

Mauri within Mātauranga Māori – earlier accounts

Like many important concepts within Mātauranga Māori, 'mauri' has a diversity of uses and meanings that apply in different contexts. These add depth to its usage within many cultural settings. For example, there are important speeches on the marae, where one of the men will call for attention with the cry, 'Tihei mauri ora!' as the speaker's life force is alive.[3] He will then proceed to introduce himself and his iwi and will speak about how we are all bound together, drawing upon Māori creation stories featuring the breath of life.

Within Māori culture, knowledge and beliefs were passed on to the next generation by oral means, with key teaching reinforced in songs, oral histories and whakapapa. When this teaching was written down, we have some opportunities to gain an insight into how concepts such as 'mauri' were viewed at the time. Edward Shortland, who travelled widely in

Source	Definition
Williams' Dictionary 1st Ed. (1844)	The heart
Williams' Dictionary 3rd Ed. (1871)	The seat of fear
Williams' Dictionary 5th Ed. (1917) Williams' Dictionary 7th Ed. (1971)	1. *Life principle, thymos of man*. Called sometimes mauri ora; 2. *Source of the emotions*; 3. *Talisman, a material symbol* of the hidden principle protecting vitality, mana, fruitfulness, etc., of people, lands, forests, etc.
Raupō Dictionary of Modern Maori, P.M. Ryan (2012)	Life principle, special character, moon on night 28, talisman
Te Aka Maori Dictionary https://maoridictionary.co.nz/ (current)	1. (noun) life principle, life force, vital essence, special nature, a material symbol of a life principle, source of emotions - the essential quality and vitality of a being or entity. Also used for a physical object, individual, ecosystem or social group in which this essence is located.

Table 1. Selected dictionary definitions of 'mauri'

New Zealand in the 1840s, recorded the following account of ceremonies for a young man, whose chiefly father had passed away:

"My father is dead. I buried him. I have come to you to perform the ceremonies of the *pure* and the *horohoro*, to remove my sacredness….. In the evening, the hair being cut, the *mauri*,[1] or sacredness of the hair, was fastened to a stone.

[1]The hair of the head, in this ceremony, was made fast to a stone, and the sacredness of the hair was supposed to be transferred to this stone, which represented some ancestor. The stone and hair were then carried to the sacred place belonging to the *Pa*."[4]

This account links to more modern customs in which a spiritual presence is passed on to a mauri stone, which is then placed in a building or in an environmental setting to provide protection for that domain. One example is the mauri stone of pounamu gifted by Ngāi Tahu to the All Blacks rugby team, and which can be seen in Auckland. "The stone embodies the team's mana and offers them protection in their travels and on the field….Guests to the All Blacks Experience are encouraged to touch the stone. Over time the stone collects the positive thoughts and wishes of manuhiri and in this way the mauri and support of the nation is passed on to the All Blacks."[5]

Various definitions of mauri were collated by Elsdon Best (1856-1931), who recorded spiritual terms and concepts, mainly from his time amongst Tuhoe during 1895-1910. These understandings were included in later editions of a *Dictionary of the Māori Language*, compiled by William Williams. In a 2007 PhD thesis on Elsdon Best, Jeffrey Holman includes a full chapter on 'Best's bequest: mauri in Best, and the post-mortem literature', including its relationship to Williams' dictionaries and later understandings.[6]

The earliest editions of Williams' Dictionary referred to mauri simply as 'the heart', and later as the 'seat of fear' (Table 1).

This link of mauri to the emotions, particularly sudden emotions, sat alongside other understandings of the material talisman in which spiritual power was invoked. Best examined more metaphysical meanings, including 'mauri ora' as applied to human health, and made an analogy with the Greek concept of 'thymos', an emotional element that moves within people and ceases at the death of the body.[7]

This understanding of mauri as the animating 'life principle' came to be the lead dictionary definition, in Williams' dictionaries from 1917,[8] and in contemporary dictionaries [9] (Table 1).

At this point, it can also be noted that similar concepts to mauri have been found in other Pacific Islands, as also recorded by Elsdon Best. The widespread use indicates that mauri is an ancient concept that pre-dates the journeys of Māori to Aotearoa:

"The *mauri* is termed the *mouri* in some dialects; it is the *mauli* (life, soul) of Wallis Island, the *mauri* (to live) of Efate, and *mauri* (Soul, mind) of the Paumotu Group. Certainly the *moui* (life) of Niue is connected with this *mouri* or *mauri*."[10]

Indeed, we find contemporary discussions of 'mauli ola' in the context of native Hawaiian health, where mauli means life, heart, spirit, our essential nature, and ola means well-being, healthy.[11]

A leading expert within Ngāi Tahu at the end of the 19th century was Hōne Taare Tīkao (1850-1927), who was placed in the care of two Ngāi Tahu scholars (tohunga) for his education and was one of the last to receive instruction in this way. Tīkao was later involved in a national movement, Te Kotahitanga, for an independent Māori parliament, and was renowned as a source of traditional learning.[12]

Around 1920 he was interviewed by Herries Beattie (1881-1972) and described many old traditions. This included the following account of mauri:

"The *Mauri* might be called the knowledge that was held within the *Wairua* (soul) of man or the animating principle of anything – it is very hard to describe in English. I cannot say how far this principle went. The *tohungas* would interpret it in the *Whare-mauri,* the chief school and seat of the highest education of the Maori.

The *Mauri* could proceed anywhere – its *Karakia* (set petitions) could touch the bush, hills, deep sea, rocks, rivers, mountains and anything else. *Karakia* can proceed all over the world. Besides invoking the *Mauri* of anything, the skilled *tohunga* could take it away from anything. He could take it from a man – the man would die; he could take it from the bush – the bush would die; he could take it from a mountain – the mountain would fall. If he took the *Mauri* of the sky there would be excessive rain, snow or tempests. The knowledge of *Mauri* started from the heart of man and went through everything, so that is why the teaching of the *Whare-Mauri* was so important."[13]

The importance of the concept within Māori learning is apparent here, along with a difficulty many express in being able to explain it. Some further perspectives are provided within the writings of the Rev. Māori Marsden (1924-1993), who was not only an Anglican minister, but also a graduate of the whare wānanga of Te Aupouri. The following descriptions of mauri would indeed imply that mauri is present in all matter:

"Whilst all the created order partook of *mauri* (life force, ethos) by which all things cohere in nature, in human beings this essence was of a higher order and was called *mauriora* (life principle). This essence (mauri) I am convinced, was originally regarded as elemental energy derived from the realm of *Te Korekore*, out of which the stuff of the universe was created."[14]

"Tohi whakahā, or tohi mauri, is the enduement of mauri (life principle) by infusion (whakahā) of the breath (manawa)…..Sickness and death resulted from the depletion of the natural vital force through the agency of the gods or evil spirits, and this mauriora had to be replaced through the tohi mauri."

Rev. Māori Marsden

"*Tohi whakahā*, or *tohi mauri*, is the enduement of mauri (life principle) by infusion (whakahā) of the breath (manawa)…..Sickness and death resulted from the depletion of the natural vital force through the agency of the gods or evil spirits, and this *mauriora* had to be replaced through the tohi mauri."[15]

"Immanent within all creation is *mauri* – the life-force which generates, regenerates and upholds creation. It is the bonding element that knits all the diverse elements within the Universal 'Procession' giving creation its unity in diversity. It is the bonding element that holds the fabric of the universe together."[16]

Further concepts from Māori Marsden's writings are reminiscent of those of the Jesuit palaeontologist Teilhard de Chardin (1881-1955), who developed ideas about the noosphere as a thinking envelope that builds upon the earth's biosphere and is directed to an ultimate omega point.[17]

In the cosmology of Māori Marsden, mauri is given a role connected with the consciousness of Papatuanuku, the Primordial Mother and personification of the Earth, and reliant on Io, the Supreme God who initially existed alone in Te Korekore:

"The function of humankind as the envelope of the noosphere – conscious awareness of Papatuanuku – is to advance her towards the omega point of fulfilment….Mauri as life-force is the energy within creation which impels the cosmic process onwards towards fulfilment. The processes within the physical universe are therefore 'pro-life' and the law of self-regeneration latent within creation will, if not interfered with, tend towards healing and harmonising the eco-systems and biological functions within Mother Earth."[18]

We can thus see the influence of goal-directed and contemporary spiritual ideas upon the thinking of Māori Marsden during the 1970s. We can associate this with the phase of Mātauranga Māori classed as colonial/religious, in which there is adoption of a monotheistic tradition and increasing abstraction in the way a deep thinker like Māori Marsden was able to create new ideas.[19] Other modern ideas can be seen in additional reflections made by Marsden, and the special insights that ancient seers (tohunga) were able to provide, including their ability to focus mauri into specific areas of the environment:

"The means of accomplishing this was the task of the tohunga who by his knowledge and art drew forth the mauri of the universe and concentrated it within a stone or some other object which was then secretly placed within the area – forest, sea, river. From this source, the aura of the mauri would radiate outwards both to the environment and more specifically to the particular species for which it was intended……Those with powers of spiritual insight and perception (matakite) perceived mauri as an aura of light and energy radiating from all animate life. It is now possible to photograph this mauri in living things”.[20]

These passages immediately bring to mind claims made that the aura of an object could be photographed under the right conditions, as in Kirlian photography where a high voltage is applied to an object exposed to a photographic plate.

Another important contributor to our understanding of the Māori worldview is Sir Mason Durie (b. 1938), the psychiatrist who has made an enormous contribution to Māori health. A 2001 publication is entitled, *Mauri Ora. The Dynamics of Māori Health.* While not a treatise on mauri itself, the preface to the book provides interesting reflections on mauri:

“Mauri, a major theme in this book, embodies two concepts. First, far from being static it implies a dynamic force; and second, it recognises a network of interacting relationships. Though the mauri of each object is separate, they share at least two commonalities: energy and vitality.

"No rock, or river, or tree, or person is entirely dead; shape and form are maintained by the spatial arrangements within cells, between cells and across the whole, and the mauri may be conceptualised as a total energy package adding value to the individual components, creating as it were an integrated life force and conferring a meaning beyond the vision of the human eye. Moreover, in the end the mauri of one object retains its momentum not because of its intrinsic qualities alone but because of its relationship with the mauri of others.”[21]

In constructing a Māori psychology, Mason Durie gives a further role to mauri in relation to encounters on the marae and associated psychological attributes:

"No rock, or river, or tree, or person is entirely dead; shape and form are maintained by the spatial arrangements within cells, between cells and across the whole, and the mauri may be conceptualised as a total energy package adding value to the individual components." *Sir Mason Durie*

“The mauri, the life force, spirals outwards seeking to establish communication with higher levels of organisation and to finding meaning by sharing a sense of common origins. Meaning comes not so much from analysis of the differences as from the discovery of similarities.”[22]

As in the writings of Māori Marsden, mauri functions to achieve an ultimate purpose or goal, be that towards an omega point of fulfilment (Marsden), or through communication and shared meaning at a higher level (Durie).

NCEA resources

To assist teachers preparing the NCEA Level 1 science course, a number of resource links are provided within Course Outlines where mauri is described (particularly numbers 3 and 4).[23] These contain a number of descriptions of mauri that have already been set out in this article, including that mauri is a person’s life force and is related to spiritual wellbeing.[24]

Associations are made between mauri and “the more intangible things that influence human systems, such as culture, emotional and spiritual connections”, with the view that mauri requires holistic thinking and “highlights the fundamental relationship between people and the rest of nature.”[25] Likewise the Department of Conservation publication on Biodiversity Strategy is provided as a link, with the following perspective:

“Mauri can be understood as the life force or life essence and is intrinsically linked to whakapapa (genealogy). Everything has a mauri and it plays a crucial role in the interconnectedness and ordering of elements within whakapapa.”[26]

A further understanding of mauri is contained within additional links, where scientists have considered the effects of pollution and remediation on waterways. In an article entitled *Dirty Rivers Destroying Mauri of our Oceans*, we are encouraged to think of mauri as follows:

“Mauri in this instance is best understood as ‘the life-supporting capacity of the waters and environments’ – if the water is muddy and you can’t see into it – its mauri is compromised; if the river is choked with weed – its mauri is compromised; if you drink water and it makes you ill, its mauri is compromised.”[27]

This approach to relate mauri to the ‘life-supporting capacity’ of a waterway, is similar to the way that we might comment on the ‘health’ of a river to describe how well fish could survive or how safe the water is to drink. However, a claim is also made in the same article that mauri is a ‘universal concept’, even though no supporting examples are provided:

“We don’t need techno-scientific data to tell us that it is compromised – we can see it, we can feel it. So although mauri is a Māori word, it is a universal concept….”[28]

A related approach has been taken in another example our teachers are

Definition	Would require that 'Mauri is present in all matter'.	References
The sacredness of a person or ancestor	No	4
The heart	No	6
Seat of fear/ Source of the emotions	No	6
Life principle/ Thymos / Life force	Yes, unless restricted to living beings	7,8, 16, 26
Talisman, a material symbol of the hidden principle	No, only in selected objects	7,8
The knowledge that was held within the *Wairua* (soul)	No	13
Elemental energy derived from the realm of *Te Korekore*	Yes	14
The bonding element that knits all the diverse elements of the universe/ binding force	Yes	16, 31
The energy within creation that impels the cosmic process towards fulfilment	Yes	18
A dynamic force that promotes recognition of interacting relationships	No	22, 25
The life-supporting capacity (of rivers or the environment)	No	27, 30
Special nature, special character	Yes	9

Table 2. Summary of definitions of 'mauri' and requirement to be present in all matter

provided with; that of environmental mishaps such as the 2011 Rena disaster, where a container ship struck the Astrolabe Reef in the Bay of Plenty, releasing oil into the environment. An interesting index has been developed by engineer, Dr Kepa Morgan, using a mauri-based model to create the 'mauri-o-meter'. This measure rates various dimensions to wellbeing, including environmental, cultural, social and economic wellbeing.

"In our assessment, we can assess an indicator or a range of indicators… if it's not 0, it will either be positive or negative. For instance, if it's positive but it's only a partial enhancement, that will score +1. If it's negative but it's only a partial diminishing of the mauri, then it will score a -1. At the extremes, we're heading towards scientific tipping points, really there is no result other than -2."[29]

The model has been applied in other contexts and is promoted as a holistic and comprehensive approach to inform responses to environmental issues.[30] In an earlier publication Morgan provides more background to mauri (references 17, 19 and 20 are to the writings of Māori Marsden and reference 18 is to a publication by Mason Durie):

"The land, forests, waters, and all the life they support, together with natural phenomena such as mist, wind and rocks, possess mauri.[17] Mauri is the binding force between the physical and the spiritual [18] and is a holistic concept central to Maori thinking due to its representation in the genealogy of creation. The creation story narrative refers to mauri existing in the original seed, pulsing as the life principle [19] impelling the shoot to emerge in its quest for being. Mauri is the force that interpenetrates all things to bind and knit them together and as the various elements diversify; mauri acts as the bonding element creating unity in diversity. [20]…..When actions impact negatively upon the mauri of something, this essential bond is weakened, and can potentially result in the separation of the physical and spiritual elements resulting in the death of a living thing or alternatively the loss of a thing's capacity to support other life."[31]

Compatibility of these meanings with modern chemistry

We thus find within Mātauranga Māori definitions of mauri that are interrelated but which have specific features (Table 2). The next question is how compatible these are with modern chemistry, and could one or more of these understandings have sufficient support to be used within the Big Idea that 'Mauri is present in all matter'?

For a number of these the answer would be 'no', due to their connection with the emotional life of humans. Other definitions derived from the cosmology of Māori Marsden would require that mauri is present in all matter but rely on a 'bonding element' or 'elemental energy' that have not been substantiated within chemistry and physics.

The definition of 'mauri' specifically as 'special nature' or 'special charac-

Submitter Code	Points made in the Submission
ANON-767U-41GJ-F	I have a major issue with Big Idea 4 - in particular the concept that all particles have mauri. The issue with this is that it seems to be a way to use a Maori world view to explain a concept that did not exist as part of matauranga - namely the particle nature of matter. Using mauri as a way to explain attractive forces seems to be a step backwards and introducing a level of pseudoscience to this concept. Furthermore, as a Maori chemist, I find this to be almost an offensive level of cultural appropriation.
ANON-767U-41DM-F	A fundamental axiom of science is the rejection of this kind of essentialism of 'life force' as a useful concept to explain the empirical world. It is axiomatic because it used to be a widespread view among scientists, but the experimental evidence conclusively proved that it does not, empirically, exist.....Of course, mauri is a very useful concept for us to make decisions about upholding the rights of individuals, or when allocating resources to biodiversity, conservation and environmental management. Students in Aotearoa should know about it.
ANON-767U-4E1Q-M	Under this definition Mauri appears to be a supernatural concept (and it may be understood as such in Te Ao Maori) and by definition supernatural concepts cannot be considered part of science - this is not only true of "western" science, but all science. There are similar problems with the concept of "whakapapa".
ANON-767U-4EAN-1	This is asking me as a teacher and scientist to teach akonga a hypothesis that is not the most powerful nor all encompassing hypothesis. The teacher's responsibility is not to deal with beliefs. As a scientist my job is to make the distinction between belief and research knowledge clear.
ANON-767U-4SV5-B	This is a cultural concept with many layers to its meaning. Science students should be able to reach Excellence using their scientific understanding, rather than their ability to successfully link to aspects of te ao Maori.
ANON-767U-4EZ8-4	While the idea that each particle has it's own identity and characteristics as an individual as well as part of a whole is good, mauri is not the right word for it. Not everything has mauri (life essence), especially not inanimate objects, which will likely be the focus of this standard.

Table 3. Feedback Statements from the Chemistry and Biology Phase 2 Survey in 2021.

ter', provided in more recent dictionaries, [9] could apply to the Big Idea in the sense that particles at the atomic or molecular level retain their identity through chemical processes, but this definition was not supplied in the NCEA glossary.

Regarding the lead idea of mauri as 'life force', the short answer again is that chemists have never found evidence for a life force at the atomic or molecular level. Physics has uncovered 4 fundamental forces to date (gravitational, electromagnetic, strong and weak),[32] without which the chemical elements and life itself would not be possible, but no separate life force. Past considerations of the élan vital posited by Henri Bergson (and the gradual downfall of vitalism), or of related concepts from traditional cultures (e.g. Ki from Japan or Ch'i from China), have not resulted in their inclusion within modern chemistry or biology.[33]

How the Big Idea within NCEA has developed to date

The NCEA subject development has been open for comment and review, with public submissions received in 2021. The raw feedback for Phase 2 of NCEA level 1 Chemistry and Biology can be viewed online, for which 76 responses are recorded. Of these, 28 specifically criticised the inclusion of 'mauri' in Big Idea 4, while no submission argued for its inclusion.[34] Six of the anonymous submissions are provided in Table 3. These critiques speak for themselves, and reflect a consistent view that evidence is lacking for including a 'life force' concept within chemistry teaching.

A response to this feedback was provided by the Chemistry and Biology Subject Expert Group (SEG). Within 'Theme Two' on 'Further clarification of mātauranga Māori concepts required', no mention is made of mauri specifically, despite this being raised by over a third of the submissions, but instead the following response is provided:

These critiques speak for themselves, and reflect a consistent view that evidence is lacking for including a 'life force' concept within chemistry teaching.

"Mātauranga Māori concepts have been incorporated in the subject content, reflecting the requirement for mana ōrite mō te mātauranga Māori in the NCEA Change Package. The SEG will review materials to ensure that the use of these concepts is clear and appropriate. The glossary will also be reviewed and the explanatory notes within the standards better utilised to support the interpretation of these concepts when used within a standard. The SEG notes that the Course Outlines and Assessment Activities include links to resources that support upskilling around these concepts."[35]

The argument appears to be that the concept of mauri will stay, given an appeal to the principle of 'mana ōrite mō te mātauranga Māori', that is of parity or equal status for Mātauranga Māori within the NCEA change package. Teachers need to upskill in their understanding of the concepts involved. The question can be raised whether this is a political directive taking precedence over the scientific intuition of the large number of people who criticised the inclusion of mauri during the Phase 2 feedback process.

The lack of expectation that concepts taken from Mātauranga Māori into the chemistry and biology curriculum should stand up to the evidence normally expected of these sciences in an international context is concerning. The response also seems to go beyond earlier statements about the purpose of 'mana ōrite', designed to enable more Māori students to succeed in the sciences, indeed a very important goal, and the key changes to be made:

"Ensuring that, where possible and appropriate, te ao Māori and mātauranga Māori are built into achievement standards for use across English and Māori-medium settings. That might mean: having Māori-centred contexts for exemplars and assessment resources e.g. local iwi history."[36]

What needs greater consideration from this statement is the "where possible and appropriate" provision. If the change does not respect the integrity (or mana) of the subject, here chemistry, surely it is not appropriate to bring that concept into NCEA teaching at that point.

My own view is that the 'mauri' is a fascinating and deep concept within Mātauranga Māori, but that it does not belong within a curriculum strand on chemical attractive forces.

Conclusions

My own view is that the 'mauri' is a fascinating and deep concept within Mātauranga Māori, but that it does not belong within a curriculum strand on chemical attractive forces. At the same time, the values inherent in mauri are applicable within the wider curriculum, for example in promoting the 'life-supporting capacity' of waterways to improve the environment. This would be one example where the interests of green chemistry and environmental chemistry, developing rapidly within many chemistry departments, and Mātauranga Māori can be mutually supportive.

Are there other examples of chemistry that can be brought from Mātauranga Māori into the chemistry syllabus, and thereby make the content more attractive and engaging to students? Interesting historical examples can be found in the chemistry of pigments and dyes used in rock art, clothing and cosmetics, in the medical properties of molecules found in native plants (rongoā Māori) and aspects of traditional food chemistry and preservation. Scientific explanations can then be added to show how and why those practices worked.

At the same time, the chemistry curriculum should match international standards in evidence-based content and levels of competence, to ensure our school leavers and university graduates strive for excellence, and thereafter work most effectively for the development and prosperity of their communities.

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Sensory science: digitally unlocking the subconscious response

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Keywords: *sensory science, aroma, taste, haptic technology, artificial intelligence, virtual reality, augmented reality*

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Her research group, the Larsen Lab in the School of Chemical Sciences (SCS), uses a combined approach of traditional and bespoke sensory evaluation techniques with the latest haptic technology, artificial intelligence and machine learning to investigate the dynamic sensory experience of food and beverage consumption, sensory profile complementarity, consumer preference and the relationship between sensory properties and aroma and flavour compounds.

Introduction

Sensory science is defined as "a scientific discipline used to evoke, measure, analyse, and interpret reactions to those characteristics of food and other materials as they are perceived by the senses of sight, smell, touch, taste, and hearing".[1]

From its post WWII origins, sensory science has relied on trained human panellists and consumers to self-report their perceptions and preferences through questionnaires and scales of various types. Focusing on the key attributes of food which drive our nutritional and hedonic choices - appearance, texture, aroma, and flavour - panellists are actively engaged to rate their response to these attributes during a process which is innately passive in terms of hedonic evaluation and in many instances the result of a subconscious choice.

With the need to disengage the "conscious" response, a natural facilitator is digital technology. Utilised in many non-invasive forms from intelligent haptics to sensors, virtual reality (VR), artificial intelligence (AI) and machine learning, the digital revolution is heralding the biggest shift in a rapidly changing and exciting future for sensory science.

Technological developments: measuring human senses in the digital space

Touch

Consumers are immersed in the digital world. Visual and audial information have long been the primary engagement, but as user interfaces on phones and tablets become almost exclusively touch screen, the progression of haptic technology has rapidly improved. Also called 3D touch or kinaesthetic communication, haptic technology creates an experience of real touch by applying forces, vibrations or particular motions directly to the user's body.[2]

Haptic devices can also include sensors that directly measure the forces exerted onto the interface by the user, similar to a pressure sensor. Some of the simplest haptic technologies are gaming accessories such as joysticks and steering wheels used to simulate the motion of flying a helicopter or steering a race car. The use of haptic technology in sensory science is in its infancy but it can drive novel investigation into how we sense through touch by creating controlled haptic objects in the virtual space.

Human touch is generally divided into three sensory orders: kinaesthetic, cutaneous and haptic, with perception via kinaesthetic and cutaneous denoted as tactile perception.[2] Though the sense of touch can be passive or active,[3] haptic is mostly associated with active touch used to communicate such as indicating a response, carrying out an action or organising objects.

Innovative pieces of haptic hardware are now pouring onto the market, fuelled predominately by the popularity of immersive gaming, which has the added benefit of brand competition and keeping prices in check, opening a myriad of opportunities to use this technology in research.

The company Ultraleap, founded in 2019 after the merger of Leap motion and Ultrahaptics, has built on the popularity of innovative haptic technology by creating plug-and-play hardware for touchless haptics and interaction devices "to create digital worlds that feel human".[4]

Their ground-breaking touchless technology utilises ultrasound waves to create mid-air tactile sensation – virtual objects feel "real". In brief, when a person's hand is placed in mid-air above a flat module equipped with several small ultrasound speakers, the speakers are individually triggered via an algorithm to release ultrasound waves at different times to the same space, i.e. your hand.

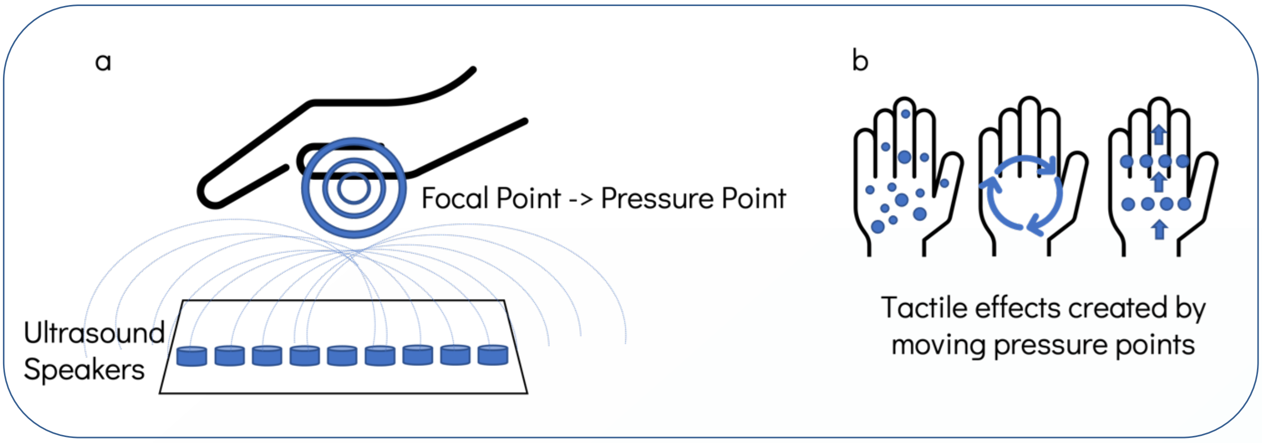

Fig. 1. a: Ultrasound waves emitted from speakers create a focal point on a hand in mid-air. Here the ultrasound waves cause a small depression on the skin, a pressure point that creates a detectable vibration. b: Pressure points are moved around the hand creating different tactile effects.[4]

The ultrasound waves coincide at a focal point in 3D space, which can instantaneously move around in whichever way it is programmed to do so. The combination of ultrasound waves at this focal point has enough force to depress your skin ever so slightly, the resulting pressure point then causes a vibration which is able to be detected by your skin's touch sensors (Fig. 1).

By simply moving the pressure point around your hand, a vast array of mid-air tactile effects can be created, lines and shapes can be sensed and 3D controls formed. A great advantage of using this technology is removing the need for what is now becoming old-fashion wired sensors on a person's hands to exert vibrations and measure forces, that are less likely to facilitate in natural hand movement.

Ultraleap's haptic technology can also convert any existing screen into a "touchless" screen, allowing consumers to interact with the interface using 3D virtual controls and without having to physically touch a screen. This has many applications in the public space, the obvious in COVID-19 times as a hygienic way to use a public kiosk, ATM, etc. But for sensory science, and in particular when working directly with consumers, this also allows researchers and companies to use haptic technology to give consumers an immersive digital experience with their products.

"The most significant power-loss mechanisms are spectral losses, as the sun emits a wide range of wavelengths of light and single junction p-n type solar cells are only capable of absorbing photons of a specific energy as dictated by their bandgap."

Applications include allowing a consumer to virtually feel the texture or springiness of a product prior to purchasing for example. Ultraleap's aim is to create a "touchless, natural, memorable and emotional" sensory experience.

Now that it is possible to use mid-air hand gestures to control response, it is becoming a reality to use natural hand movements for data collection in sensory science research. Touch is now a key digital sense and is going to be more important in sensory science data collection.

In the near future, a sensory panellist may be able to indicate a response to a particular food or beverage via a pressure sensor with vibration feedback or swipe a mid-air virtual scale with an increased feeling of drag as the scale nears its upper terminus. Consumer studies may be able to move into the home or workplace, using motions that are familiar through smartphone use for rating products in their normal environment or on-the-go, adding another layer of authenticity to sensory research.

Wearable motion tracking devices have long been used in sensory science to monitor how consumers interact with products. These devices, that can often be bulky and cumbersome, attach to the hands, face, lips or head and through various techniques can record the movement of a consumer while they interact (as naturally as possible) with a product or its packaging. Data on muscle and joint movement can be collected to understand consumer behaviour and preference.

In the last twenty years, technology has markedly improved the way in which researchers can detect and analyse motion. Jaw tracking devices are one of the most commonly used motion tracking systems to assess food texture and sensory experience. The biggest developments in this area have come in the form of accelerometric and gyroscopic[5], electromagnetic[6] and optoelectrical approaches[7].

Of these, optoelectric devices are generally the most portable. Researchers have in the past relied on high-end filmmaking technology where a consumer eats while surrounded by several high definition cameras all simultaneously recording vertical and horizontal jaw movement, including a head mounted camera facing the participant to record finer facial movement[8] but this comes with a hefty price tag and bulky equipment. Smaller and more economic optoelectric methods utilise a detection camera to capture the motion of small infrared LEDs that are attached to a participant's jaw, face and neck while they consume food.[7]

Infrared tracking devices, regardless of whether they are wired or wireless, are still invasive to the participant, adding some weight to the body and are not conducive to a natural sensory experience. Furthermore, these types of motion tracking often require further in-depth analysis from researchers with coding skills so they can write their own scripts and programs.

For studies where movement on a more simple scale is investigated, mainstream wearable motion trackers such as fitness bands, smart watches and inertial sensors can be used. Recent technological advancements have markedly improved accuracy and accessibility.9

When mounting inertial sensors and proximity sensors such as radio-frequency identification (RFID) on a participant's arm, wrist and/or hand, researchers have been able to successfully monitor the frequency of food and beverage intake and eating behaviour patterns by simply identifying and quantifying specific hand-to-mouth gestures that accompany food and beverage consumption.[10] Limitations of using these devices include finer movements not being detected – sneaky snacks can be missed.

The virtual hand model can be incorporated with a VR headset, enabling the user to see their "own hands" in real time in the virtual world as they perform all manner of movements while interacting with virtual objects.

A recent breakthrough in hand tracking devices came from Leap motion (now Ultraleap Inc.), when they created what is currently the most advanced wireless and touchless hand tracking device on the market.[11] It utilises infrared cameras, artificial intelligence and neural networks to essentially create a pair of "digital hands". Their hand tracking software is purposely designed to capture accurate subtle and intricate movement in as natural a way as possible.

The unit consists of a small controller equipped with two cameras and infrared LEDs. When a hand is placed above the device in mid-air the LEDs illuminate it with infrared light. As the LEDs pulse the camera takes images; the frame rate and pulses are synched. Data are simultaneously sent back to a computer where the tracked movement of the hands is visualised as a virtual skeletal hand model. The software models all the bones and joints in the hand as well as fingertips and palm and is able to predict thumb or finger position with great accuracy even if they are obscured under another part of the hand.

The virtual hand model can be incorporated with a VR headset, enabling the user to see their "own hands" in real time in the virtual world as they perform all manner of movements while interacting with virtual objects. This includes using virtual gestures to control operations – pinch, stretch, throw, grab and squash in the exact motion of your hands with zero latency. It is purported that the interaction becomes so real that the user forgets they are not their real hands. A marketing strategy or truth? Time will tell as researchers will surely find innovative uses for this product in the near future. A major potential with this application in sensory science is using the virtual hands to navigate food in a virtual world - something that is clunky with the current VR hand controllers as they are not suited for the subtle and intricate hand and finger movements that are associated with evaluating food by the sense of touch.

Aroma and taste

Aroma and taste are the next senses in line to be "digitalised" and, unsurprisingly, these are most likely the hardest to simulate in the digital or virtual space. The premise of the "metaverse" – a digital utopia - is just that; all of our human senses fully immersed and accessible in a digital and virtual universe, but this does not yet exist.

With respect to aroma, aroma generators are the closest we have so far. Simple ways to incorporate aroma into an immersive space are generating an aroma during a VR experience such as during immersive virtual reality (iVR) where the whole ecosystem of a particular venue is simulated right down to olfactory, auditory and tactile stimuli.

An example is a study contrasting an iVR coffee shop with a traditional sensory booth during hedonic ratings of different coffee samples.[12] The aroma of cinnamon buns was dispersed through the virtual room by bubbling air through a concentrated liquid food flavour. This, among other cues, resulted in significant differences in hedonic response and preference order of coffee samples.

The researchers noted that the hedonic data collected from the iVR coffee shop was "more discriminating and a more reliable predictor of future coffee liking" and that consumers were "more engaged in the testing when evaluating coffees in the virtual coffeehouse, an outcome that likely also contributed to improved data quality".

One of the latest ventures into "digital aroma" ran afoul of the FDA. A start-up called FeelReal designed a sensory mask with a cartridge that clipped under the eyepiece of VR headsets.[13] Vials of food safe "liquid flavour" were loaded into the cartridges as defined single aromas or in different combinations to create unique aroma blends in order to enhance the total sensory experience in VR. The sensory mask was primarily created for use with video games and movies watched through VR headsets, enabling the user to smell the aroma of gunpowder or smoke during a battle sequence in a game or experience the aroma of the food the actors are eating, the smell of fields of wildflowers or an ocean breeze while watching a movie.

However, because the aromatic liquid is essentially the same as what is used for e-cigarettes and is vapourised for inhalation, the headset has been classed in the same bracket as e-cigarettes and vaping devices. The crackdown on flavoured vape products has caused a halt to production with a new design required if they are to carry on to the production phase. Other than the aroma generator, FeelReal's sensory mask had other functions to fully immerse the user in VR such as misting capabilities to let you experience the spray from a waterfall, micro cooling fans to simulate wind on your face while you ride a virtual motorcycle down a road, micro heaters to simulate the heat of a desert and haptic vibration feedback for virtual impacts.

The turning point in accessibility to this technology for private use and research is quite recent due to the significant reduction in cost over the past few years as more brands of VR headsets, AR glasses and accessories have come onto the market.

After FeelReal's now infamous FDA ban, other aroma masks have pursued the gap in the market. Another start-up OVR (olfactory VR) technology has created a cartridge that clips onto VR headsets and wraps around the users nose.

Inside the cartridge are vials of "scent" that interact with VR scenarios, for example when you virtually pick a rose and sniff you smell the scent of a rose, but as soon as you move the virtual rose away from your nose the smell disappears. Unlike a perfume the scent doesn't linger due to the way the hardware is designed.[14] Using scents rather than an vaporising device to deliver the sense of smell in VR means the OVR cartridge shouldn't have issues with the FDA. OVR also produces malodours for VR training simulations such as firefighters navigating building fires while smelling smoke.

With technological roots in the 20th century, VR and augmented reality (AR) are revolutionising how we perceive and interact with different forms of digital information.[15] VR displays create a totally immersive virtual environment based around computer generated images and this virtual environment has a large enough field of view that the virtual experience is sufficient without having to rely on the users real environment.[15] AR displays on the other hand give the user a "see-through" projection in the enhanced real environment - essentially virtual images are overlapped with real background images crafting a world of fiction and reality.[15]

The turning point in accessibility to this technology for private use and research is quite recent due to the significant reduction in cost over the past few years as more brands of VR headsets, AR glasses and accessories have come onto the market. Sensory science has played a big part in the development of this technology and its applications.[16] VR and AR are now mainstream, with consumers often interacting with AR without realising it. Applications of AR include when you shop online for sunglasses and by following onscreen prompts create a 3D image of your face to give you a realistic idea of how the sunglasses fit your face before purchasing, or visualising a different hair colour or style on yourself before committing to a visit to the salon.

VR and AR usage is now commonplace in some branches of sensory science research. Fig. 2 shows an explanation of how both are used in consumer testing of beer in a pub.[17]

In the real-world environment, consumer testing of hedonic response may be carried out in a pub or in a sensory booth in the traditional sense without digital technology. In an AR environment, the base layer is the real world overlaid with digital information that the consumer can see by looking through AR glasses or on a smartphone screen (just like in the viral AR game Pokémon Go).

Thus, a consumer can still interact with parts of the real world that are augmented in the virtual environment while being simultaneously immersed in a virtual/digital world. In the pub scenario, AR could overlay nutritional or production information over the beer that the consumer can read while they drink or a consumer could wear a VR headset that depicts a virtual pub while consuming a real beer.

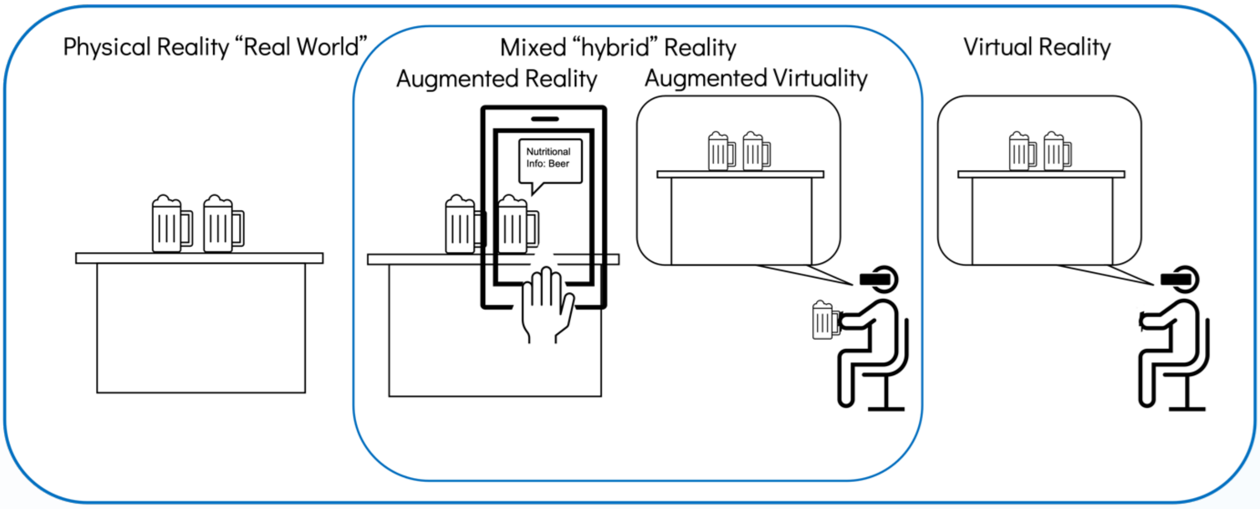

Fig. 2. Different scenarios of "tasting a beer at the pub" in the real world, in augmented reality and in virtual reality. [17]

In contrast, a VR scenario is completely removed from reality. Studies in this space could involve consumer preference by ordering a virtual beer in the virtual pub or undergoing a sensory evaluation of their expectations of a virtual beer in the virtual pub[17] – they don't actually taste anything physical. The early sensory science studies were mainly VR and this is still the norm. However, AR is expanding its reach as a useful tool due to consumers or participants being able to consume real food and beverages while being visually placed in the virtual world. In a way, this is our best attempt so far at digitalising the sense of taste.

The sky is the limit with the type of virtual environments that can be used for sensory evaluation with the rise in popularity of 360 degree cameras. These cameras allow the researcher to physically record any real life environment in the 360 degree space and then recreate that in the virtual world.

The latest generation cameras enable the 360 degree videos to be stitched together in camera, meaning little editing work is required to recreate locations and objects in the virtual world. However, for the researcher who has coding skills there is a multitude of ways to tailor virtual environments to facilitate non-invasive sensory evaluations.

The latest generation cameras enable the 360 degree videos to be stitched together in camera, meaning little editing work is required to recreate locations and objects in the virtual world.

The COVID-19 effect

During the COVID-19 pandemic a lot of wet lab research ground to a halt under the strict lockdown protocols of many countries. However, sensory science was in a position where it could take advantage of the internet and conferencing software such as Zoom to move sensory panels and consumer evaluation online and into people's homes.

Makeshift sensory booths were created or not at all and testing continued with much concern over context effects; the time of day, immediate surrounds, sample preparation and how this would affect discrimination and hedonic response.

Italy was one of the first countries to go into lockdown in early 2020 and the Italian Sensory Science Society developed a concurrent research project called the "Remote Sensory Testing" project, which involved 6 sensory labs around the country with the aim of investigating the validity and effectiveness of remote sensory tests versus those undertaken in a traditional lab or sensory booth location.[18]

They developed protocols for panel leaders to control the sensory evaluation sessions when remote testing, which would often occur over live Zoom stream.

They studied the effect of remote testing on trained panellists undertaking the triangle test and tetrad test, descriptive analysis and Temporal Dominance of Sensations and on consumers using Check-All-That-Apply and hedonic tests. Interestingly, they found that there were no significant differences between results collected remotely and from the sensory booth in all trained panellist data apart from the tetrad test and no significant difference for consumer data.

This poses the question, can sensory science leave the booth for good in the future? Technology is certainly facilitating this possibility and with the rise of smaller and cheaper VR/AR tech and as artificial intelligence expands its reach this could be a real possibility sooner rather than later.

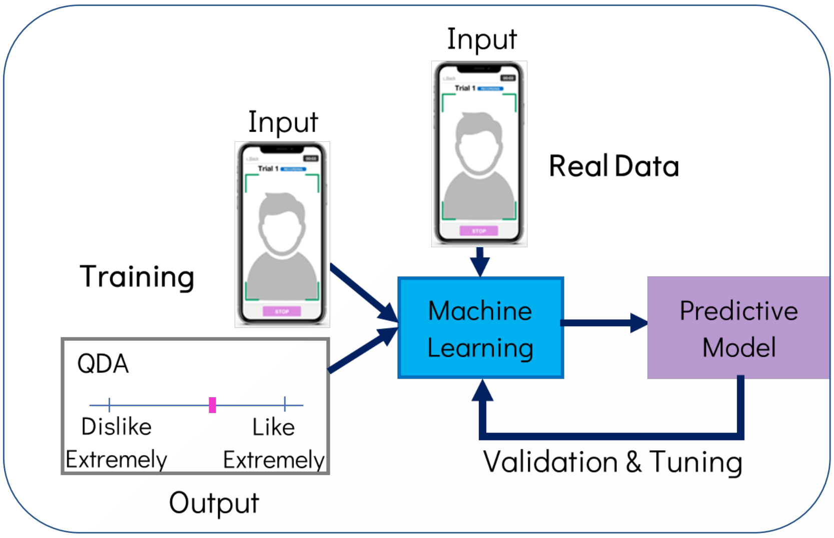

Fig. 3. Schematic example of a predictive model of consumer experience using facial expression. A training dataset of videos collected from consumers is independently validated with a hedonic questionnaire and used to build a model that with a different set of data (test dataset) can predict hedonic response.

Embracing AI and the changing face of a sensory scientist

The sensory scientist of the future is no longer a traditional sensory lab researcher but is also computer savvy, with either the ability to code or at least having strong computer science/software engineering collaborations. There is more crossover between the two disciplines with the first publications of data mining in the combined chemical, food and sensory science space[19] and bespoke sensory science applications appearing in the literature.

A key area where artificial intelligence could come to the forefront in food and sensory science is its predictive power for consumer perception and preference. Artificial intelligence is generally used for its ability to identify patterns from big datasets and one of the first areas of development for AI was image and video processing to predict, based on a training set of data, outcomes from a "real" dataset (Fig. 3).

The sensorial-hedonic response to a stimulus such as a food or beverage is usually classified by an indirect, language-based evaluation of the sub-conscious reaction to the stimulus. In other words, in sensory panels, panellists are required to express with words how the stimulus makes them feel.

> Facial expression recognition is an excellent example of how AI can be used to predict consumer preference and hedonic response via their own smartphone in their own home, under the same conditions they would normally consume food/beverages.

It has been suggested that this sensorial response can be directly linked to the universe of imperceptible human micro-expressions, which last only a fraction of a second, they themselves being a direct response of the sub-conscious.

While impossible to observe at the human eye level, in a consistent manner, machines, through deep-learning and more generally AI paradigms and algorithmic workflows, can help to efficiently capture the relation between sensorial-hedonic response from food tasting and facial muscle and tendon movements.

With future potential to move out of the lab for some sensory evaluation methods, smartphone apps are gaining interest with their ability to provide remote evaluation. Facial expression recognition is an excellent example of how AI can be used to predict consumer preference and hedonic response via their own smartphone in their own home, under the same conditions they would normally consume food/beverages. However, while sensory response "labels" have been built within a space of attributes that are far from the canonical descriptions used by sensory science in response to food (for example "happiness", "sadness", "surprise", "anger" and "disgust"), new efforts to direct the existing and continuously evolving deep-learning field towards the sensory lexicon are needed.

Moreover, the association of micro-expression characterisation with electrical signalling propagated by the brain (i.e. EEG) and measurable by now widely accessible and inexpensive headsets can constitute a powerful tool for sensory science. These highly technological based approaches, if supported by a strong cross-collaborative effort across disciplines from food to computer science, can determine a paradigm shift for sensory science, with the field moving towards direct communication to and from consumers rather than embracing an indirect translation of sensation to consumers by way of trained panellists.

■ Conflict of interest statement: The author has no association with any of the companies or brands mention in this article.

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Article

CRISPR: the best bet for a better world

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Keywords: *gene editing, Nobel Prize, hereditary diseases, food production*

Introduction

They first met in 2011 at a conference in Puerto Rico and thought it would be fun to collaborate on CRISPR.[1] Nine years later Emmanuelle Charpentier and Jennifer Doudna (Fig. 1) won the Nobel Prize in Chemistry. Seldom has a major scientific discovery been rewarded so quickly.

Why is CRISPR so impressive? Why are over 6000 research institutes,[2] publishing 20 papers a day[2] using CRISPR? Undoubtedly the prime reason is its wide-ranging applications. It has the potential to cure a large number of hereditary diseases, solve the world's shortage of food, adapt crops and animals for the climate change, and rid us of pests such as mosquitoes, locusts and rats.

Fig. 1. Emmanuelle Charpentier (left) and Jennifer Doudna (right) were awarded the 2020 Nobel Prize in Chemistry. Image sources: https://commons.wikimedia.org/wiki/File:Emmanuelle_Charpentier_2020.jpg published under CC BY-SA 4.0 and https://en.wikipedia.org/wiki/Jennifer_Doudna#/media/File:Jennifer_Doudna_-_26658740020.jpg published under CC BY 2.0 licenses respectively.

What is CRISPR?

CRISPR (pronounced "crisper") stands for clustered regularly interspaced short palindromic repeats. The role of the CRISPR system is to protect bacteria from viruses. Bacteria that survive a viral infection keep part of the viral DNA, which is stored in the bacterial genome between CRISPR sequence repeats.

If the same virus invades again, the bacteria now have a complementary RNA sequence that guides a Cas9 nuclease to cut the viral DNA, stopping the infection. Scientists can make their own versions of CRISPR RNAs, which guide the Cas enzymes to cut specific genes. In other words, CRISPR-Cas acts as genetic scissors that precisely edit or alter specific genes.

Fig. 2 shows the CRISPR-Cas9 system. The short CRISPR RNA (crRNA) sequence matches the DNA target sequence. The part of the crRNA that is complementary to the target sequence is called the spacer. The tracrRNA acts as a scaffold to link the crRNA to Cas9 endonuclease (shown as a brown silhouette). The other essential part of the system is PAM (protospacer adjacent motif) which is a short (2-6 nucleotides) DNA region 3 nucleotides upstream from where Cas cuts the DNA strand.

The Cas9 nuclease, isolated from Streptococcus pyogenes, recognises a PAM sequence of NGG (where N is any nucleotide base and G is Guanine). If the target region does not have NGG then Cas9 cannot act. However, there are many different Cas endonucleases (e.g. Cas12, Cas13) each isolated from a different bacteria, and each one recognises a different PAM. For example, Cas9 from Staphylococcus aureus (SaCas9) recognises the PAM, NNGRRT (where R is a purine, T is thymine).

Fig. 3 illustrates the X-ray structure of the DNA double-helix (blue and magenta) being acted on by CRISPR (orange) and Cas endonuclease (grey).

CRISPR is a gene editing technique that can be used to treat more than one gene at the same time. It need not involve adding DNA from a different species into the genome, which could result in unintended or undesirable consequences. It can be used in any living organism - animals (including humans), plants, bacteria and yeasts. CRISPR is cheaper and faster than other gene editing techniques.

Medical applications

Diseases

There are thousands of hereditary diseases involving a single gene defect that CRISPR has the potential to cure. They include sickle cell disease, haemophilia, cystic fibrosis, muscular dystrophy, phenylketonuria, multiple myeloma, hereditary diffuse gastric cancer, hypercholesterolemia, haemochromatosis and Huntington's disease.

Life-threatening diseases such as Huntington's disease, Duchenne muscular dystrophy and Tay-Sachs disease have no effectual treatment. In others, the cures are problematical: liver transplant for haemophilia, lung transplant for cystic fibrosis, bloodletting for haemochromatosis, removal of the entire stomach for diffuse gastric cancer.

Millions of children in Africa are born with sickle cell disease and most will die before they reach adulthood. Blood is taken from the patient and the pluripotent stem cells are gene edited using CRISPR to knock out the defective gene, and the blood returned to the patient.[3] Matthew Porteous reported[4] that 70% alteration was sufficient to obtain a cure in mice.

It is too early to know how long a cure lasts. Encouragingly, the first person given the treatment for sickle cell disease is symptom-free after three years. Human clinical trials have begun in the USA on sickle cell disease and another blood disorder, beta-thalassemia,[5] in which an abnormal form of haemoglobin results in the destruction of red blood cells leading to anaemia. There are about 80,000 cases worldwide. Additional clinical trials using CRISPR are underway in China, the USA and other countries for conditions including leukaemia, multiple myeloma and sarcoma, lymphoma, type 1 diabetes, urinary infections, hypercholesterolemia and male pattern baldness.[6]

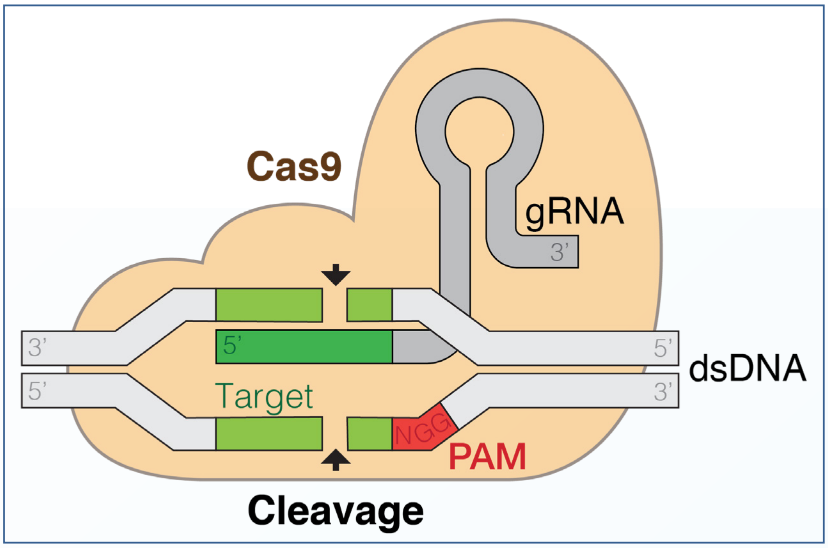

Fig. 2. Schematic representation of how CRISPR-Cas9 functions. The Cas9 endonuclease (brown silhouette) interacts with two small RNAs. CRISPR RNA (crRNA, dark green) matches the DNA target sequence (pale green). The part of the crRNA that is complementary to the target sequence is called the spacer. The second tracrRNA (gRNA, grey) links the crRNA to Cas9. The other essential part of the system is PAM (protospacer adjacent motif, red) which is 2-6 nucleotides of the DNA (in this example N = any nucleotide and G = guanine). Cas9 cuts the DNA strands precisely 3 nucleotides upstream from PAM. Image source: https://commons.wikimedia.org/wiki/File:GRNA-Cas9.png, published under CC BY-SA 4.0 license.

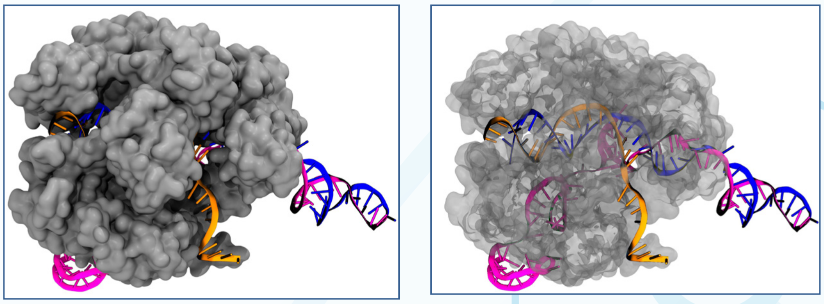

Fig. 3. X-ray crystal structure of CRISPR-Cas9 in complex with single-guided RNA and DNA primed for cleavage. In (A) the molecular surface of the protein is shown in grey, CRISPR RNA is shown in orange and the DNA strands are shown in blue and magenta. In (B) the protein surface is shown transparent. The structure is published in the protein data bank (accession code: 5F9R, reference: 10.1126/science.aad8282) .

Skin is readily accessible and CRISPR/Cas9 can be used to treat a collagen gene defect that causes the extremely fragile skin disease known as butterfly skin.[7] About 500,000 cases are known. The transformed cells can be incorporated into lab grown human skin which will be used to replace the patient's lost skin.

While treating blood and skin is relatively straightforward, other organs such as the liver, pancreas, kidneys and brain are more challenging. To access the liver, CRISPR-treated stem cells incorporated in fatty nanoparticles were carried by the blood system to pass through the target-cell membranes.[8] This procedure is under industrial development.[9] Initially using mice,[10] hereditary blindness was treated by injecting into the eye a virus that produces a CRISPR system. This has led to a human trial.[9] Recent reviews[11] describe additional delivery systems for different organs, and further medical applications.

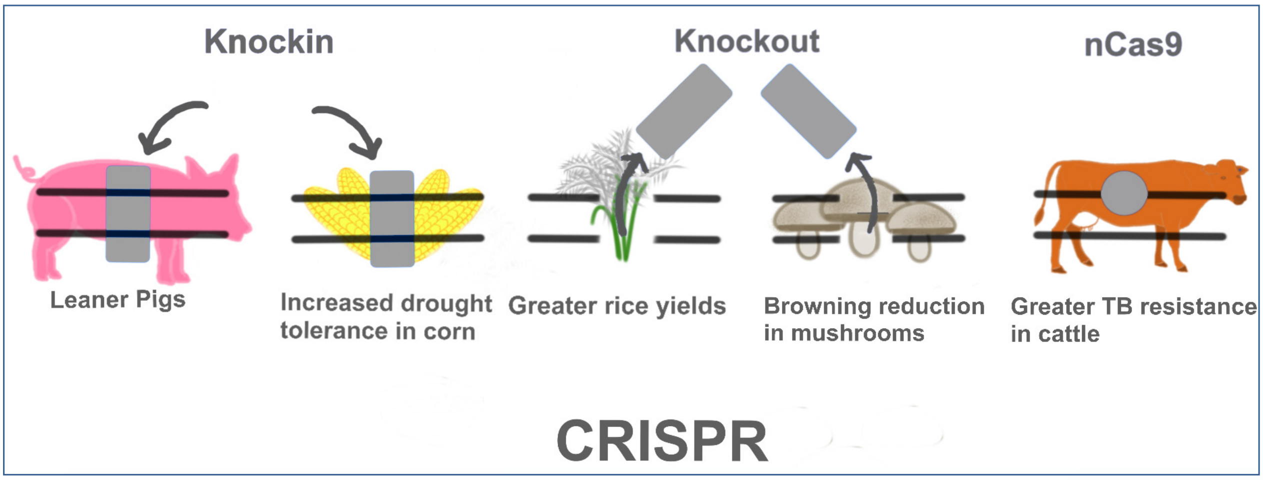

Fig. 4. Applications of CRISPR-Cas9 technology to agriculture and food production.[13]

Pig transplant organs

There is a worldwide shortage of human organs for transplants. Pigs offer the best alternative but there is the problem of introducing foreign antigens that cause the transplants to be rejected. CRISPR can solve the problem by altering key genes.[12] In New Zealand, AgResearch scientists are investigating the production of transplant organs from pigs using CRISPR.

Feeding the world and climate change

The world population reached 8 billion in July 2022 and is expected to increase to 9.7 billion by 2050. There are already food shortages in parts of the world. The Guardian Weekly (27 May 2022) reported a global food crisis due to climate change, food insecurity, rising prices, the war in Ukraine and warned it would change our world. 100 million people received food aid in 2019, before the COVID-19 pandemic, but the number close to starvation was 135 million and it is now estimated at 276 million, while 810 million go to bed hungry every night. These figures do not take the war in the Ukraine into account.

CRISPR has the potential to help deal with both the population expansion and global warming. CRISPR can be applied to all aspects of food production[13] (Fig. 4). It has been used to increase the yields and other desired traits of crops representing the three major grains: wheat,[14,15] corn[16] and rice.[17] Gluten-reduced wheat has been achieved for use in bread for people with coeliac disease.[18]

CRISPR has a crucial role in assisting plants and animals to adapt to increasing heat and drought caused by global warming.

Pork with less fat has been developed.[19]

Tomatoes bought in supermarkets can be tasteless because they are harvested too soon. Using CRISPR, the softening enzyme pectate lyase was turned off, [20] so the tomatoes can be left on the vines longer to develop their attractive taste.

Probably the first gene edited food was high oleic acid soybean oil with longer frying life,[21] which came on the market in the USA in March 2019. However, it was gene edited by a method called TALEN, generally a slower and more expensive technology than CRISPR.

Potatoes stored at low temperature turn an unattractive brown when fried at high temperatures to prepare chips. Gene editing avoided the breakdown of starch to glucose which leads to the browning reaction, and also reduced acrylamide formation.[21] These potatoes have been on sale in the USA since 2019.

CRISPR has the potential to aid food and agriculture in even more ways (Fig. 5), including breeding plants that are disease or herbicide resistant.[22,23] Because CRISPR systems are a natural defence against viruses, they are ideal for stopping viral infections.[24] CRISPR can be used to facilitate the production of bioactive compounds[22] such as lysine, beta-carotene, lycopene and D-pantothenic acid.[25]

CRISPR has a crucial role in assisting plants and animals to adapt to increasing heat and drought caused by global warming. Drought and salt tolerant soybeans are being developed by the United States Department of Agriculture's Agricultural Research Service and corn with very high amylopectin starch is being prepared by DuPont.[26] Alleles (gene variants) that are observed in a domestic plant (such as tomato) can be re-created using CRISPR to improve the yield of a drought resistant wild variety.[27]

In New Zealand, AgResearch has committed to a program of producing heat tolerant cows with increased milk production and lower greenhouse gas emissions. Scion is investigating CRISPR technology for improvements in Pinus radiata production.[28] Plant & Food Research is using CRISPR to edit flowering[29-30] and ripening related genes,[31] with the aim of the research being to reduce the time needed to breed perennial plants and to increase the storage life of fruit.

Additional uses

CRISPR is basically a DNA or RNA detector so it can be used to detect infectious diseases, including viral infections following transplant operations,[32] Dengue fever,[33] Lassa fever,[34] and inevitably Covid-19. A number of CRISPR-based tests for SARS-CoV-2 have been developed including the much publicised five minute mobile phone test.[35] Researchers are exploring the use of CRISPR-based treatment for Covid-19,[36] which ideally would be effective against all potential pandemic coronaviruses.[36]

The CRISPR/Cas systems are being used to develop a wide range of biosensors for not only bacteria and viruses but also for cancer biomarkers, toxins and narcotics.[37]

CRISPR has an important role to play in food safety. Combined with the polymerase chain reaction (PCR), it can detect food poisoning bacteria, meat adulteration and genetically modified crops.[38]

Gene drives have the potential to eliminate pests such as wasps, possums, rats and stoats.[39-40] Gene drives use CRISPR to insert a dominant gene (e.g. for sterility) which spreads rapidly through the population. Over 240 million people suffer from malaria with 670,000 deaths each year. Gene drives to eradicate malaria-carrying mosquitoes[41] are currently underway in Florida and may commence in Africa shortly.

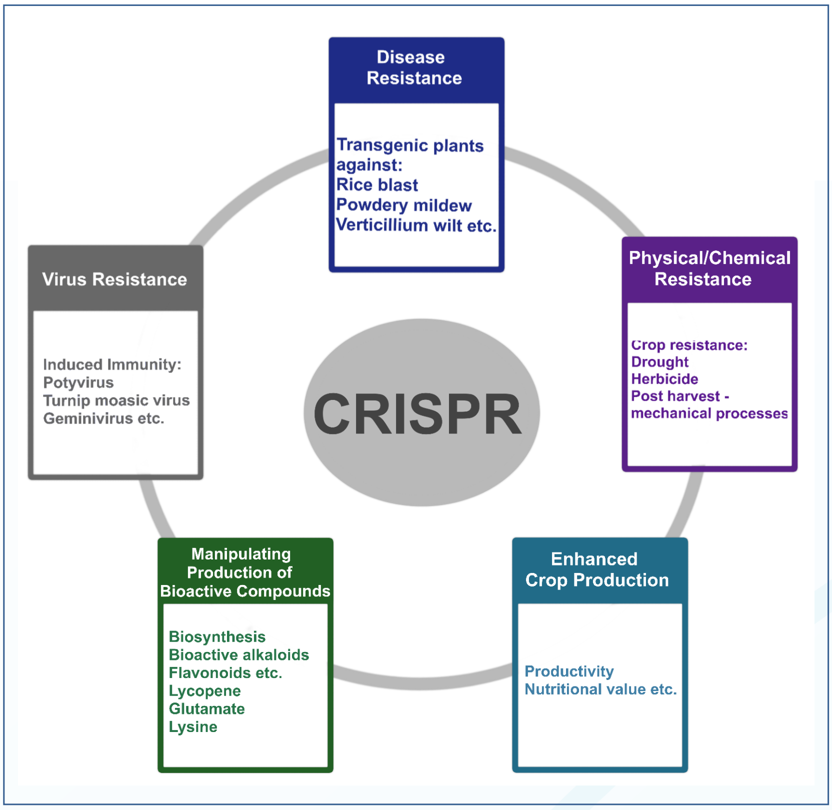

Fig. 5. Further applications of CRISPR-Cas gene-editing in food and agriculture[22]

In a brilliant example of mimicking nature, CRISPR has been used to precisely assemble five enzymes on a DNA scaffold in order to move substrates efficiently from one active site to the next in a multi-step reaction, with a significant improvement in overall yield of the antibiotic violacein.[42]

NZ regulations compared to other countries

CRISPR gene editing to improve foods is treated under the same regulations as GMOs in New Zealand. Regulations are similarly restrictive in the EU. Other countries are far less regulated in comparison.

Australia considers that the changes to the DNA are equivalent to spontaneous mutations that occur naturally, and therefore no regulations are needed. Sweden does not regard it as GMO technology. USA and Canada operate on a case-by-case basis. The USA has already approved more than ten gene edited crops as having non-regulated status. The Chinese are encouraging "scientists to proceed with courage and caution on GM research".

In New Zealand, gene editing to cure human diseases is regulated by the Hazardous Substances and New Organisms Act (HSNO Act) and the Medicines Act; consequently CRISPR is treated like a GMO. Approval of gene drives in New Zealand is almost Byzantine. The HSNO Act and the Agricultural Compound and Veterinary Medicines Act along with four other Acts have to be considered.

Concerns about CRISPR and some responses

Inevitably, concerns and objections have been raised around the use of CRISPR. Some of these relate to lack of understanding, while others require further investigation. Examples include:

- Confusing genetically modified organisms (GMOs) with gene editing by CRISPR, when in fact no foreign genetic material is involved.

  "They are mucking around with our food!" when breeding for superior varieties has gone on for thousands of years.

- CRISPR disease resistant wheat may produce altered flour, and so home recipes and industrial processes need to be changed.

- The altered genome might contain some unexpected defect. e.g. potatoes last longer but do not turn green when exposed to sunlight. As in conventional breeding, checks need to be made.

- Gene edited seeds will come with a price tag that is bad for poor farmers in third world countries.

- A disconnect between personal mistrust in scientific evidence but willingness to use newly developed drugs if a diagnosis of a serious medical condition such as cancer was made.

The idea that designer babies with superior intelligence or Olympic gold medal ability are imminent is mistaken.

- Complacency in richer countries who have enough food and do not believe CRISPR is needed.

- A gene drive on a plant or animal to control it in one location could result in the global population being affected.

  Examples include a gene drive to control the seaweed Undaria in NZ could lead to its demise in Japan where it is consumed as food; a gene drive to control wild deer in NZ could affect farmed deer; and a gene drive on NZ possums could result in the loss of Australian possums. Reverse gene drives are being developed as a precaution.

Designer babies

Concerns about CRISPR as outlined previously are various. However, perhaps the greatest objection that has arisen is the possibility of designer babies. Since the Chinese scientist, He Jiankui, used CRISPR on two embryos, the world drew back in alarm and 40 nations signed a protocol forbidding such practice. It needs to be said that He Jiankui, who was sent to jail, was not trying to make designer babies but to give them protection from HIV.

The idea that designer babies with superior intelligence or Olympic gold medal ability are imminent is mistaken. At present it is only possible to raise IQ by a maximum of 2.5 points or increase a child's height by 2.5 cm,[43] neither of which is going to come close to producing a world-beater.

We don't know enough about which genes influence intelligence or athletic ability (considering a marathon runner and a shot putter and are as different as celery and cheese) and we have no idea what genes are involved in producing a Mozart!

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Survey

Chemistry in New Zealand at your fingertips: results of a reader survey and future direction of the journal

VYACHESLAV V. FILICHEV (email: v.filichev@massey.ac.nz)

Introduction

The quarterly journal published by the New Zealand Institute of Chemistry (NZIC), *Chemistry in New Zealand* (CiNZ), is currently circulated electronically as a PDF document among NZIC members. The journal is available to the public at https://nzic.org.nz/cinz but the current issue is accessible to members of NZIC only.

As most of our readers are aware, it features scientific articles, news from NZIC branches and occasional book reviews or other general interest items. With the first volume published in 1936, is worth noting that the long history of CiNZ illustrates the significance of chemistry to New Zealand's economy and public good relevance.

Currently, the CiNZ audience and contributors are professional chemists who are generally NZIC members associated mainly with academic and industry institutions. In recent years, NZIC has seen a decline in membership subscriptions and a shift in relative distribution of members with a different status. In 2020, the Secondary Chemistry Educators of NZ (SCENZ - a national chemistry teachers' association) became an individual branch of NZIC. As a result, professional chemists from industry and chemical educators from universities and schools were connected within one organisation.

The NZIC Council recognised that this change provided a valuable starting point to involve 500+ members of NZIC to bring examples of 'real-world' chemical science and technology into the classroom of secondary/high schools and explain chemistry

A Working Group was established to deliver this project. Members of the Working Group are:

■ **Dr Vyacheslav V. Filichev** (Chair) - Associate Professor in Chemistry at Massey University. He is heavily involved in the teaching of 1st year university classes (400+ students) as well as in research (> 60 publications, several patents).

■ **Dr Catherine Nicholson** - Editor of CiNZ since 2013. She has worked as a professional chemist in New Zealand for 20+ years in a variety of roles within the CRI, university and private research sectors and is currently a Senior Materials Scientist at the Building Research Association of NZ (BRANZ). Reflecting her interest in communicating science more widely to non-specialist audiences, Catherine was awarded the Postgraduate Certificate in Science Communication by the University of Otago in 2021.

■ **Natalie Bould** - Publishing Designer of CiNZ since 2021. Natalie is an experienced journalist, communicator and designer with specialist digital publication skills.

■ **Hamish McDonald** - Treasurer of CiNZ since 2019 and a member of NZIC since 1983. He has broad strategic, commercial and operational experience, spanning senior leadership roles in quality, risk management, manufacturing, logistics, technology, science, and financial services.

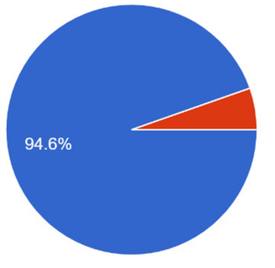
■ **Dr James Wright** - specialist chemistry teacher at Awatapu College in Palmerston North and member of SCENZ. Recently transitioned from academic research, James is aware of the void between secondary school curriculum content and real-world applications, having a keen interest in authentically delivering science to all students by making chemistry visible. At a school where approximately 30% are of Māori ethnicity, James recognises the need to honour Te Tiriti o Waitangi in this regard.

■ **Dr Joanne Harvey** - Associate Professor in Chemistry at Victoria University of Wellington. She has extensive experience in teaching at all levels of chemistry at university. Her research is focussed on organic synthesis and drug discovery, specifically on natural product-inspired drug discovery, structure-based drug design and medicinal chemistry.

■ **Dr Joanna Dowle** - originally part of the Working Group but has since resigned for personal reasons. We would like to thank Joanna for her valuable contribution at the start of the project.

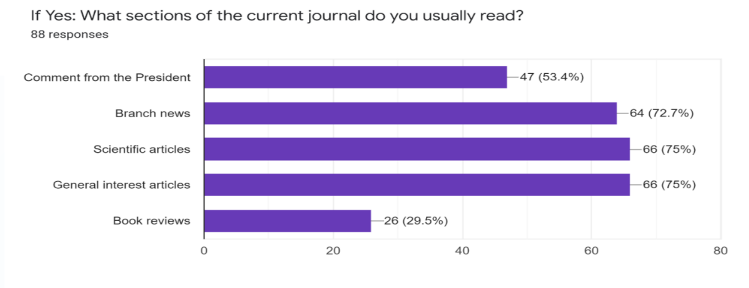
Part 1. Evaluation of satisfaction with the current journal

Have you read any part of the journal in the last two years?
(93 responses)



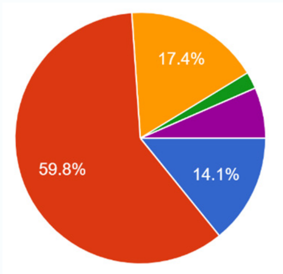
- Yes
- No

If yes, what section of the journal do you usually read?
(88 responses)



How do you rate the content of the journal?

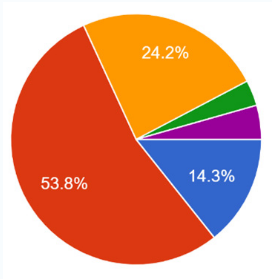
(92 responses)



- Excellent
- Good
- Average
- Poor
- No opinion

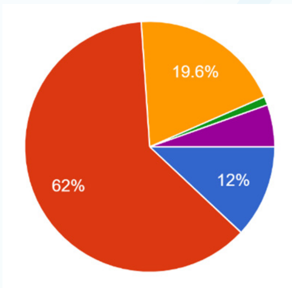
How do you rate layout and design?

(91 responses)



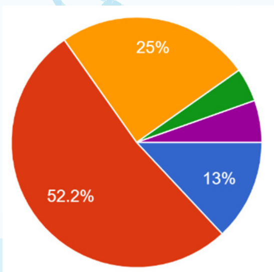
How do you rate readability?

(92 responses)



How do you rate photos, images and colour?

(92 responses)



in the New Zealand context to the public. As CiNZ is one of the main sources of distributing information from an NZIC perspective, the NZIC Council decided to revise and modernise the content of CiNZ, move it to a digital platform and make it more appealing to readers.

The aim of the proposed project is twofold. Firstly, we aim to revise and modernise the content of the journal to appeal to a much wider audience. In particular, the refreshed content will target high school level chemistry with a goal of engaging a younger audience in chemical sciences and making the journal a valuable teaching resource. Secondly, we plan to digitise the journal by adopting a web-based format that will facilitate the inclusion of interactive content and increase accessibility to more readers. This will transform the way we deliver our content, by making best use of the technology available to provide a rich information source for our audience that is visually attractive, fun and informative.

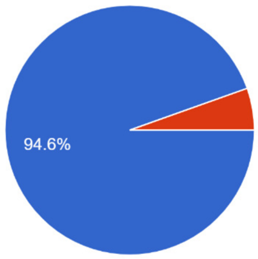
To find out how satisfied NZIC members are with the current journal and establish the level of support for expanding the target audience of CiNZ, a web-based survey was distributed among NZIC members in March 2022. We received 93 responses and would like to thank everyone who participated and provided valuable feedback. Most respondents were individual members of NZIC (78.5%) followed by school representatives (19.4 %). The survey results are summarised in Part 1 graphics.

In general, readers are satisfied with the current content of the journal, its layout, design, readability, and the quality of images and pictures. Branch news, scientific articles and general interest articles are the most read sections of CiNZ. This clearly indicates the professionalism of our authors and the current editorial team of CiNZ.

Part 2. Future direction of *Chemistry in New Zealand*

Do you support a proposal to expand the target audience of CiNZ from members of NZIC to school and university students?

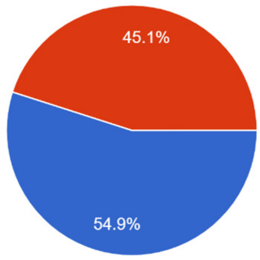
(92 responses)



Yes
No

Do you support a proposal to expand the target audience of CiNZ from members of NZIC to the general public?

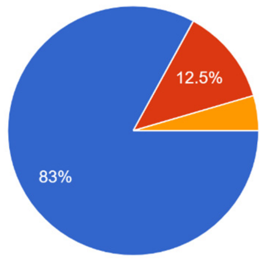
(92 responses)



Yes
No

Currently the journal is published quarterly. How often should the journal be published?

(88 responses)

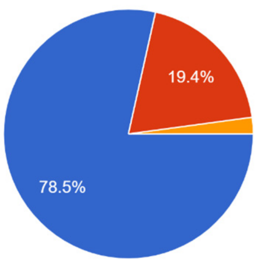


Quarterly
More often than quarterly
Less often than quarterly

Part 3. Who are you?

Are you:

(93 responses)

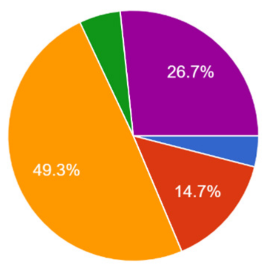


An NZIC Individual Member
A school representative
A member of the general public

If you are an NZIC individual member, are you:

(75 responses)

A student
Employed in industry
Employed in academia
Self employed
Retired
Other



Regarding the future direction of the journal (Part 2 graphics), respondents overwhelmingly supported (94.6%) the move to expand the target audience from members of NZIC to school and university students. Feedback included "*any attempt to broaden the audience is worthwhile*", "*showing students 'modern' and useful chemistry would be great!*" and "*should work to promote all NZ based chemistry and career development through secondary and tertiary teaching; academic and industrial research to a wider audience if possible*". It was also noted that the new CiNZ should "*not dilute the science totally*". Several respondents mentioned that CiNZ will need to redesign its look and content to attract that readership.

The second proposal to expand the target audience of CiNZ from members of NZIC to the general public received a mixed response: 54.9% were in agreement, whereas 45.1% were not supportive. Some respondents indicated that NZIC should educate "*the public on matters related to chemistry, promoting what chemistry is about and assisting with the demystifying of science and challenging misinformation*". Others wrote that "*this would dilute the focus too much*" and "*it would downgrade the content for members*". It is clear that the scientific content and its rigour is important for the readers of CiNZ and this fact is acknowledged by the Working Group.

Respondents of the survey indicated that quarterly releases of the journal are appropriate. They would like to read more "*general interest articles where the impact of chemistry is explained by experts*", "*articles which are relevant to NZ's primary industry*", "*articles more focused on local (NZ) specifics*" and "*articles that deal with modern research challenges*". Several people mentioned that "*a dedicated section for articles on chemistry education would broaden* *appeal to teachers (in secondary and tertiary settings)*" and that articles should include "*best practice teaching and links to the school curriculum*". Several people indicated that they are keen to provide content for the new CiNZ – we would like to thank them and will follow up in due course.

The implementation plan will include the following:

• The CiNZ working group will review the types of contributions sought and their format, allowing implementation of a new, dynamic interactive experience on the website taking examples from www.chemistryworld.com and https://cen.acs.org/ and having seamless access to the content through modern technologies, i.e. mobile phones/devices.

• The format of submissions will be revised and author guidelines updated. We envision that the new style of submissions will require a preamble written in plain English for school students to be able to grasp the ideas and concepts presented in each article.

• We will encourage submissions of visual illustrations having enhanced features (pictures in colour, 3D models of chemical structures, videos, or animations) and ask authors to provide links to websites with scientifically correct explanations of chemical terms and concepts in plain English, creating a New Zealand hub for chemistry.

• The content will populate over time with various topics which will keep the audience engaged. This will also guarantee the long-term relevance of the project. We would like to assure our current readers that involvement of professionals in the preparation of the future content and oversight by the Editor of CiNZ will guarantee scientific rigour of all contributions. The core of each article submitted should still be written based on the best scientific practices.

Exciting chemistry stories from New Zealand, along with visually appealing 3D content, will hopefully help to engage the whole whānau and thus support the development of a new and scientifically literate generation.

• To ensure information-rich content of the new CiNZ from the start, the Working Group will identify content suitable for the audience published in the last 15 years in CiNZ, currently hidden in pdf files on the website, and ask the original authors to update and give new life to these articles online.

• CiNZ also aims to provide tools for teachers showing examples of chemical concepts with significance to New Zealand which will respond to their needs identified through ongoing consultation with the SCENZ branch of NZIC.

• Initial interactions of the Working Group with the Māori science academy Pūhoro that originally started at Massey University on the Manawatū campus have identified the importance of making a current school curriculum less foreign to Māori and Pasifika students. This can be achieved by providing real-life chemistry research and development stories and examples in the context of *taiao (nature), mauri (life force)* and *kaitiakitanga (guardianship).* As many readers are aware, the new NCEA Standards currently being developed suggest an emphasis on chemistry in the context of these themes which many teachers and students are not familiar with. CiNZ aims to provide suitable tools for educators, students and their whānau. It is vital to help engage the whole whānau when students are learning scientific concepts in the class. Exciting chemistry stories from New Zealand, along with visually appealing 3D content, will hopefully help to engage the whole whānau and thus support the development of a new and scientifically literate generation.

• We suggest that every article should be equipped with hashtags and keywords taken from the relevant topics in the current science curriculum to make content more easily found.

As usual, the main obstacle in implementation of any plan is financial. Last year, we received a quote for almost $110,00 from a commercial supplier for the design and delivery of a new website. Our application to MBIE's "*Unlocking Curious Minds*" contestable fund was unsuccessful. The Working Group is trying to find ways to deliver this new project to NZIC members and any support and ideas will be appreciated. Please contact the NZIC office at nzic.office@gmail.com if you have any suggestions for how to make this project a reality.

In summary, we would like to thank NZIC members for responding to the survey and for the support of the proposal to expand the target audience from members of NZIC to school and university students. The Working Group is confident that once the new CiNZ is launched, it will attract a wider audience by describing the latest developments in chemical knowledge through extensive implementation of novel web technologies to present chemistry in the most appealing way possible.

■ **Acknowledgement:** We would like to thank the NZIC administrator, Samantha Eason, for setting up our survey on the website.

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