SEEDS OF SCIENCE:

NURTURING KNOWLEDGE FOR ALL

82ND EDITION

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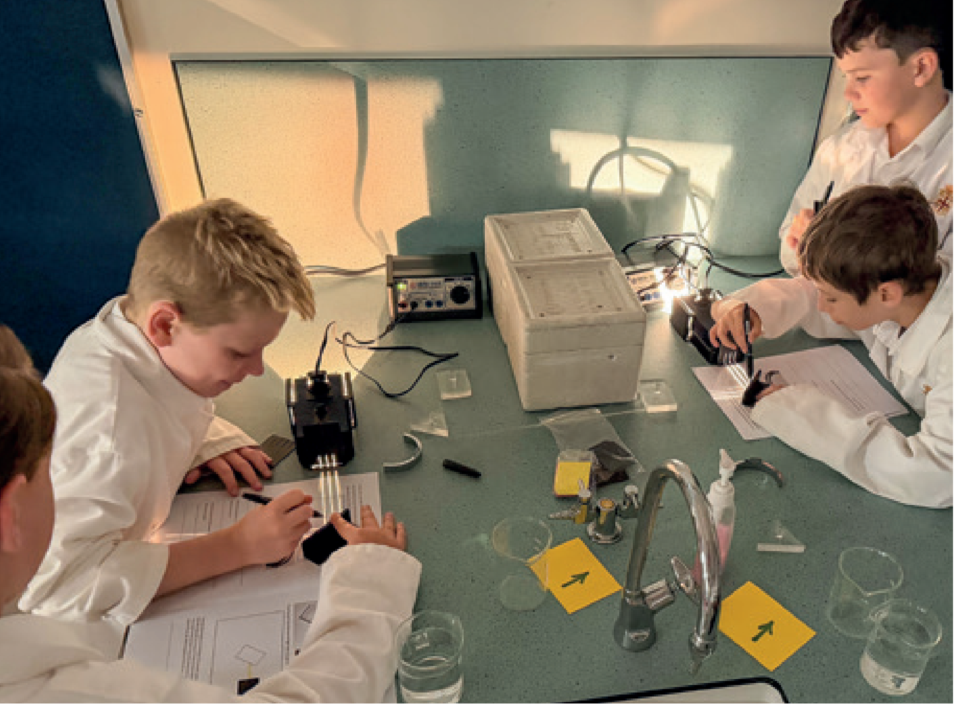
PRINCE ALFRED COLLEGE

SCIENCE JOURNAL

2026






A word from the Editor

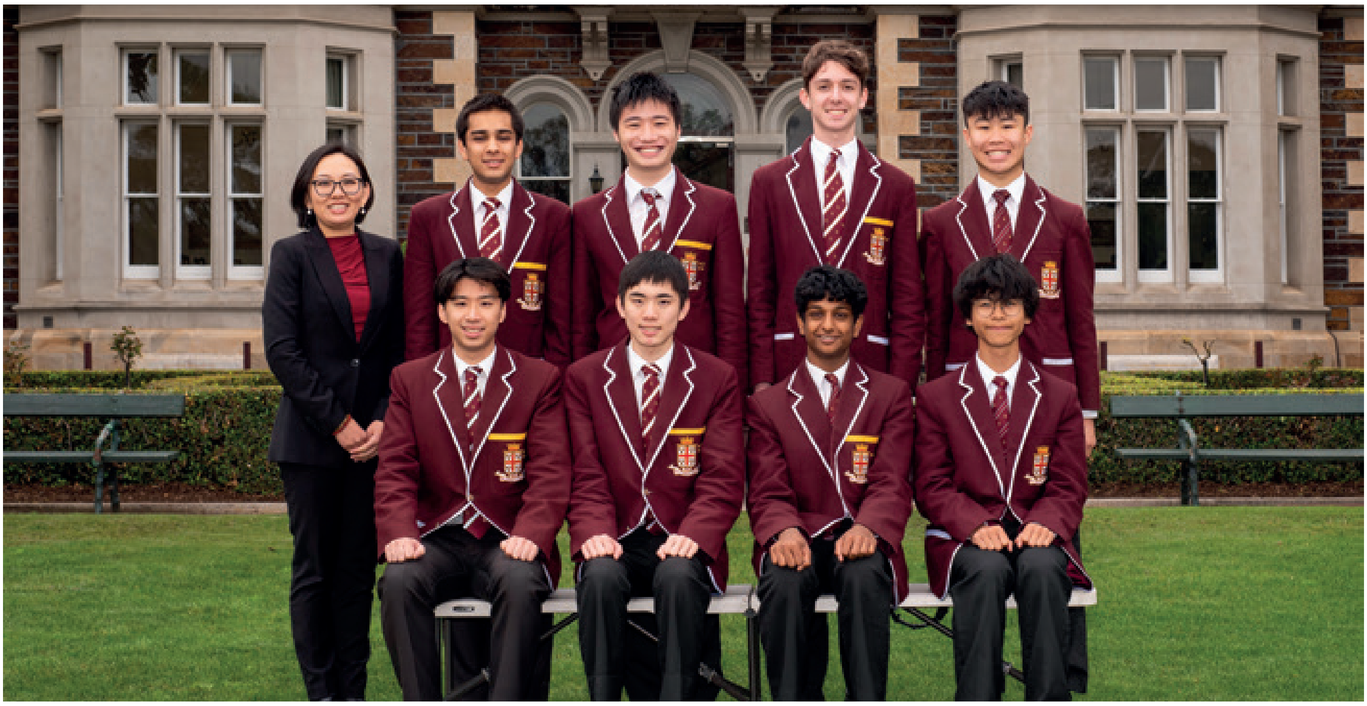
Following the chaos of 2025, the Prince Alfred College Science Journal serves as a unique opportunity for students to reflect an optimistic outlook on the world, exploring interestingly unique discoveries and sharing it with the broader community. As it enters its 82nd edition, the science journal committee continues striving to uphold Dr John West's initial vision of the journal in 1945 while acknowledging how the passage of time has developed and continued to contribute to this journal. Through this yearly publishment, we aspire to connect students, staff and parents together to celebrate the tremendous efforts the global scientific community and spread not only further curiosity but also positivity to the growingly anxious world.

The theme for this year was "Seeds of Science," prompting not only the literal discussion of the agricultural industry, but also the metaphorical interpretation of the foundations of science, allowing topics ranging from the deadly prions to utilising ion propulsion in space to be encapsulated, demonstrating the diversity in the areas of scientific research. The importance of agriculture stretches all the way back to approximately 10,000BCE, since the agricultural revolution, enabling humans as a race to produce more food than ever before. This has led rise to the ability to sustain not only much greater population sizes, but also for people to live longer lives as diets improve. Conversely, this establishes the foundation of science, as it operates not as individuals operating in solitude, but as one collaborative whole, discussing ideas and collaborating on new innovations. This theme of this edition not only allows the core application of science to benefit society to be highlighted but also demonstrate the importance of different fields complementing each other to ultimately create a discovery.

Our special guest author, Professor David MacIntyre, embodies this idea perfectly, having collaborated to achieve many discoveries such as the presence of glycans or the implications of cervicovaginal mucosal metabolomic signatures. We greatly appreciate him taking the time to out of his packed agenda to enrich this publication with his insightful information. I also wish to demonstrate my gratitude to Dr Hu on behalf of the entire science journal committee for her help organising and guiding the committee to develop this publication. The support she has offered all of us from organizing and directing meetings to drafting many students works and managing all of the development on the publisher and designer's sides despite her extremely busy schedule. Furthermore, my gratitude goes out to Taine Meyer, the designer for our journal cover this year. His incredible illustration served to neatly tie everything together in one representation, providing a perfect depiction of both interpretations of the topic. Finally, I would like to extend my appreciation to the wider Prince Alfred Community. The Science Journal is a student pioneered publication, utilised as a celebration of student curiosity, whom are the only reason the journal has continued to achieve such success year after year.

I am extremely grateful for the privilege of leading the Science Journal for 2026, being able to give back to the community while simultaneously feeding into my personal interest in the sciences. I have had the great honour of continuing the 82 year tradition this year, and I wish the best to all our young and upcoming scientists and I eagerly await their revolutionary breakthroughs in the future.

Charles Li (Year 12)
Chief Editor, 2026



2026 Science Journal Committee
Back row: Ansh Tiwari, Hugo Shaw, Finley Turner, Josh Nguyen **Front row:** Adrian Shiu, Charles Li, Minul Jayasinghe Arachchi, Josh Wang **Absent:** Saverio Blefari, Charles Tang **Staff:** Dr Di Hu - Academic Leader - Science

Front cover artwork: Taine Meyer (Year 12)

Past editors

John West, 1945

John has gone on to great heights in the scientific field of physiology. He completed a degree in Medicine at University of Adelaide before moving to Hammersmith Hospital in England. A fascination in respiratory physiology led to his involvement in Sir Edmund Hillary's Himalayan and Scientific Mountaineering Expedition in 1960-61, and the American Medical Research Expedition to Mt. Everest in 1981. Presently he is the Professor of Medicine and Physiology at the University of California, San Diego, and is actively involved with NASA in research into astronauts' physiology in space. In 2001 John was awarded membership of the American Academy of Arts and Science and he was inducted into the Princes Men Gallery. He is also a member of the Institute of Medicine of the National Academy of Sciences.

Bruce Chartres, 1946

Bruce gained top position in Leaving Honours examinations, overall and in all five subjects and followed that with a Master of Science and PhD in quick succession. He has had a distinguished academic career and his last position before retiring was as Professor of Computer Science and Applied Mathematics at the University of Virginia, USA. Sadly Bruce passed away in 2003.

Geoff Ward, 1947

Geoff graduated in Medicine from University of Adelaide in 1955. He studied Surgery and Radiotherapy at the Royal Adelaide Hospital and the Peter MacCallum Clinic in Melbourne, gaining Fellowships of both Royal Colleges. He gained further experience in Radiotherapy at the Royal Marsden Hospital in London and the Princes Margaret Hospital in Toronto. In 1970 he returned to Adelaide, where he held a visiting post in Radiotherapy at the Royal Adelaide Hospital and worked in private practice. In 1985 he was instrumental in the opening of the Adelaide Radiotherapy Centre, where he continued in private practice until his retirement at the end of 1997. Geoff passed away in 2016.

Alan McFarlane, Co-Editor 1948

After gaining a B.E. in 1952, he won a scholarship to the United Kingdom to continue his study. Alan moved to Perth and he worked as the senior process design engineer on an Australian project to provide a large natural gas plant for Indonesia. He continued working in the area of safe chemical engineering design and operation of high pressure natural gas plants. In his retirement, Alan began testing his physical capabilities on a bicycle, culminating in 2007, when he completed the Otago Rail Trail, New Zealand. Alan passed away in 2012.

Colin Schwartz, Co-Editor 1948

Colin achieved top place in examinations for the degrees of M.B., B.S. in 1954. He has since worked at the Institute of Medical and Veterinary Science in Adelaide, as the Professor of Pathology at McMaster University Ontario, and is currently Head of the Cardiovascular Department, Texas University, San Antonio.

David Prest AM, 1949

After leaving PAC, David was educated at the Universities of Adelaide, Southampton (UK), Birmingham (UK) and Oregon (USA). He holds Masters Degrees in Physics and Education. David was Principal of four independent schools including 20 years at Wesley College, Melbourne, and finished his career as Director of Foundation Studies at the University of Melbourne. In 2002 he was inducted into the Princes Men Gallery and passed away in 2018.

Bob Hale, 1950

Bob Hale graduated from Adelaide University with a First Class Honours degree in Physics in 1954. This was followed with a M.A. from Cambridge in Pure Mathematics (1958) and a Graduate Diploma in Computing Studies from Melbourne (1982). Bob taught at King's College and lectured at the Gordon Institute of Technology and the Universities of Adelaide, Deakin and Papua New Guinea. Bob is now a computer consultant.

Sandford Skinner, 1951

After leaving PAC, Sandford obtained M.B., B.Sc. and M.D. then worked in hospitals in the U.S.A. and England. Since then he concentrated on Physiology and became the Reader and Chairman of the Department of Physiology, University of Melbourne. Sadly he passed away in May 2005.

Barry Smith, 1952

Barry had an interesting, varied and exciting career. He said that this "chequered" career included teaching Mathematics and Physics at PAC, having senior positions in computing in the public service, academia and private enterprise, twice being a free-lance consultant, Assistant Secretary in the former Schools Commission, Director of a unit advising the NSW Government on technological change, heading the NSW Computer Education Unit, doing policy-oriented research in education at the ANU, statistical analysis in two government agencies, and finally being the Research Analyst at the Family Court. Barry passed away in 2018.

Michael Smyth, 1953

Michael went on to secure a First Class Honours degree in Zoology, swiftly followed by a Rhodes scholarship in 1959. Upon the awarding of his Oxford doctorate, he lectured for two years at the University of California before returning to Adelaide as Senior Lecturer in Zoology. He was the guest writer in 1966 and passed away in 1974.

Fred Symons, 1954

Dux of School, Fred went on to gain First Class Honours in Electrical Engineering and was awarded a fellowship by the General Electric Company. While studying at the University of London, he gained the Duddell Scholarship from the Institution of Electrical Engineers, London. Returning to Australia in 1964, he joined the Telecom Research Laboratories (TRL) working on a range of projects in digital networks and systems. In 1975 he was granted a Telecom postgraduate scholarship to study at the University of Essex, England for which he was awarded a PhD. In 1979 he returned to TRL as Assistant Director, Head of the Switching and Signalling Branch. Fred was a member of many Australian IT research Boards and Committees. From 1988 to 1996, when he retired, he was the Foundation Telstra Professor of Telecommunications at Monash University. Fred passed away in 2007.

Geoff Symons, 1955

In 1960 Geoff gained a B.A. in Mathematics as well as a science degree with First Class Honours in Physics. He was awarded a PhD in 1963, and a fellowship in Physics at the Kellogg Radiation Laboratories. He later spent time at New Jersey State University, the Niels Bohr Institute in Copenhagen, the Atomic Weapons Research Establishment, Harwell U.K., and Oxford University. After retirement he lectured for several years at the Open University, UK. Geoff passed away in Oxford in 2019.

John Lawton, 1956

John gained third place in the General Honours list then graduated MBBS (1962) and M.D. (1968) for research into lymphocyte metabolism. He then held positions at the Royal Adelaide Hospital, the University of Michigan and the Royal Infirmary of Edinburgh. In 1975 he joined the Department of Pathology University of Hong Kong where he attained the grade of Professor. His research in Hong Kong included immuno-deficiency in children, immunology of breast milk and autoimmunity. He retired in 1999.

Greg Bennett, 1957

Greg gained sixth place in Leaving Honours examinations followed by degrees of B.A. and B.Sc with honours in Mathematics. Post-graduate studies with the CSIRO resulted in the award of PhD in mathematical statistics. He retired from the Faculty of Mathematics at the University of Waterloo, Ontario, Canada after 31 years. Greg is still actively involved in the development of tools for data analysis using LISP as the base language.

Colin Luke, 1958

Colin was Dux of School and gained second place on the general honours list. Following on from graduating in Medicine and Surgery, he was awarded a National Heart Foundation Research Scholarship, and held positions of Senior Medical Research Officer at the University of Adelaide, Mortlock Medical Research Fellow and Honorary Virologist at the Royal Adelaide Hospital and then 15 years of private practice. Colin was engaged by Government to investigate the problem of lead exposure in young children at Port Pirie which formed the basis of a Masters Degree in Public Health. This was followed by a career as a Public Health Physician applying epidemiological principless to cancer research and in which discipline he was awarded a Doctor of Medicine. Until his retirement, he was Senior specialist Medical Consultant and Director of Clinical Epidemiology in the South Australian Department of Health. Colin passed away in 2024.

Garry Brown A.O., 1959

Garry was Dux of School and graduated from the University of Adelaide with First Class Honours in Mechanical Engineering. In 1964 he was awarded the coveted Rhodes Scholarship and went on to gain a D. Phil. from Oxford University, after which he went as a Research Fellow to the California Institute of Technology for four years. He came back to the University of Adelaide and became a Reader in the Department of Mechanical Engineering before returning to Caltech as Professor of Aeronautics. He then came to Melbourne for 9 years after he was appointed Director of the Aeronautical Research Laboratories (DSTO) before his appointment as Professor and Chair of Mechanical and Aerospace Engineering at Princeton University, USA. While at Princeton he also consulted widely in Aerospace and Defence for the U.S. In 2011, upon retirement from Princeton, he was granted Emeritus Professor, and in 2020 was awarded an AO in the Queen's Birthday Honours.

Robert Smith, 1960

Robert graduated with a B.E. in Chemical Engineering in 1965, followed by three years with ICI in Melbourne. He is now the Eastern Marketing Manager for Exxon Chemical's Additive Division in Singapore.

Geoff Trott, 1961

Geoff graduated from the University of Adelaide with a BSc, BE (Hons 1) and then from the University of Alberta with a PhD. He then spent 35 years as an academic in the University of Wollongong, finishing his working career as Sub-Dean of the Faculty of Informatics and Senior Lecturer in the School of Electrical, Computer and Telecommunications Engineering. He is currently retired and enjoying playing tennis and volunteering for Tennis Wollongong as well as travelling.

Geoff Williamson, 1962

Geoff was also Captain of the School. After Matriculation, he secured an excellent academic record while completing a M.B., B.S. A period in general practice in Whyalla followed, leading him to be Head of the Accident and Emergency Department at the Modbury Hospital. After serving as Director of Medical Services at Maroondah Hospital in Ringwood, Victoria, Geoff is currently Director Clinical Services atRockingham General Hospital, in W. Australia.

Richard Nicholls, 1963

Richard passed away during his third year of a Chemistry degree at Adelaide University.

Adrian Wilson, 1964

In 1965 Adrian gained the Elder prize for first year medicine and completed the degree in 1968, with Honours in Psychology. The years since have been spent studying and teaching history in the United Kingdom.

John Loxton, 1965

Dux of the School, John completed a B.Sc. at Melbourne University and was awarded the Wyselaskie Scholarship, followed by a M.Sc. and PhD from Cambridge University. In 1988 he was appointed Professor of Mathematics at Macquarie University and in 1995 was inducted as Deputy Vice Chancellor (Academic). John left Macquarie University in 2007 and moved to Western Sydney University. He is now an adviser to a number of independent Institutes of Higher Education in Sydney.

Rob Hall, 1966

Rob studied Medicine at University of Adelaide and trained in Neurology at the Royal Adelaide Hospital and Flinders Medical Centre. He was Clinical Teaching and Research Fellow at The Montreal Neurological Institute in 1980. He worked in private practice as a Consultant Neurologist at Memorial Medical Centre until his retirement in mid 2023 after more than 50 years in clinical medicine. He has been a member of the PAOC Management Committee for more than 26 years and was President of the Association in 2000.

Malcolm MacDonald, 1967

Malcolm graduated from University of Adelaide in 1973 with a degree in Computing Science and Applied Mathematics. At one stage, he was senior advisor to the Algerian Minister of Petrochemistry on computer applications for oil exploration. Five years were spent at University of Adelaide lecturing on Computer Engineering until invited to the Norwegian Institute of Technology. His time now is largely spent as a consultant in real-time monitoring and control.

Lindsay Packer, 1968

A B.A. in Pure Mathematics and Logic at Adelaide University followed Dux of School and fourth place in Leaving Examinations in 1968 for Lindsay.He completed a M. Sc. at Oxford University and then began Operations Research at Imperial College, London. In 1992 he completed his PhD at the University of Texas. Lindsay hasspent time at the D.S.I.R. in Wellington, New Zealand and has held positions at the University of Texas, University of Charleston and is currently Associate Professor at the Metropolitan State College of Denver.

Phil Thomas, 1969

Phil moved into several fields including truck contracting and plant propagation. 1978 saw him join the Supply Section of the Road Transport Agency, where he is now the Administration and Finance Officer, Supply.

James Cooper, 1970

James graduated with an MBBS and PhD in Immunology from the University of Adelaide. After a period of research overseas, which included time at Oxford and Harvard Universitiesand the Max Planck Institute, Freiburg, James returned to clinical practice in Adelaide. He retired from practice in 2010 and completed an MA in Art History at the University of Adelaide. He remains a director of Coopers Brewery.

Nick Birrell, 1971

Nick graduated from Flinders University with B.Sc. (Hons) and M.Sc. degrees and from King's College, London University with a Ph.D. in mathematical physics. Following a 30-year executive career in technology and finance and several years as a Professorial Fellow at Monash University, Nick now works through his private company, Kintan Pty Ltd in the fields of venture capital and consulting. Nick is involved as an advisor or director in a number of companies in fields ranging from tourism and agriculture to biotechnology and private equity. Nick was guest author in the 2008 Science Journal with an article entitled "SCIENCE, INNOVATION AND HOW TO GET RICH".

William Lee, 1972

William completed Medicine at University of Adelaide. Upon returning to Australia in 1985, he trained as an anaesthetist and is now in private practice in Lismore, NSW.

Jamie Cooper AO, 1973

Jamie was in the inaugural cohort of medical students at Flinders, did postgraduate studies in medicine, anaesthesia and intensive care medicine at Royal Adelaide, and then a critical care research fellowship at University of British Columbia, Canada. He is now Professor of Intensive Care Medicine at Monash University, an NHMRC Practitioner Fellow, Director of the ANZIC Research Centre and Deputy Director of Intensive Care at the Alfred Hospital Melbourne. He enjoys building and leading large national/international clinical research trials, aiming to improve outcomes for critically ill patients, and has published 7 original research papers in the New England Journal of Medicine.

Bill Griggs AM ASM, 1974

Bill completed Medicine at Adelaide and then specialist training in Intensive Care and Anaesthesia. He gained a tertiary qualification in Aerospace Medicine from Otago University in 2000 and completed an MBA from Adelaide University in 2009. He held multiple positions including Director of Trauma Services at Royal Adelaide Hospital, State Controller (Health and Medical) for disasters, and Director Air Force Health Reserves for SA and WA. He was deployed as both a civilian and a military officer on multiple occasions including to the Gulf War in 1991, East Timor in 1999 and 2007, both the 2002 and 2005 Bali Bombings, the 2004 Asian Tsunami and the 2009 Samoan Tsunami. In 1989 he invented a surgical instrument and technique (the "Griggs technique") to create a breathing passage through the neck. This technique was used on Pope John Paul II and is now used around the world. He was the South Australian winner of the Australian of the Year award in 2006 and the South Australian of the Year in 2009. He was awarded the honorary title of Emeritus Professor by the University of Adelaide in April 2024. He is a member of the Princes Men Gallery.

Dr Alan Branford, Co-Editor 1975

Dr Alan Branford was born at Henley Beach near Adelaide, South Australia, in 1958. He was educated at Prince Alfred College and the University of Adelaide, graduating Bachelor of Science (Honours) and Master of Science in Mathematics. Alan was awarded a PhD from the University of Cambridge, U.K., in Applied Probability in 1983. From 1984, he lectured Mathematics and Statistics at Flinders University in Adelaide, retiring as an Associate Professor in 2016.

David Hone, Co-Editor 1975

David graduated from University of Adelaide in 1979 with Honours in Chemical Engineering. He worked as a refinery engineer in Australia, then spent a time in the Netherlands until he based himself in the UK working for Shell Trading. He is now Chief Climate Change Adviser for Shell, with a focus on carbon capture and storage and the use of carbon pricing policies globally.

David Weller, 1976

David Weller completed Medicine at University of Adelaide in 1982 and undertook his PhD at Adelaide and Nottingham. From 1995-2000 he was senior lecturer, Department of GeneralPractice, Flinders University. In 2000 David was appointed Professor and Head of the Department of General Practice at the University of Edinburgh.

Randell Brown, 1977

After completing Medicine at Adelaide in 1983, Randell began specialist training in Radiology, with his final year at Hammersmith Hospital, London. He is now in general practice in Adelaide, and visiting specialist in Radiology at the Queen Elizabeth Hospital.

Michael Coats, 1978

Michael commenced a Law degree before he completed a Bachelor of Arts in English Literature and then undertook post-graduate study.

Graham Slaney, 1979

Following completion of Medicine at Adelaide University, Graham worked in the UK andNewfoundland, Canada, for several years. He was searching for 'real' winters, and the opportunity to pursue further medical trainingin Anaesthetics and Obstetrics. He has now settled in Mansfield, Victoria, as a country GP. He works at Mount Buller during the winter which enables him to perform some emergency medicine (and ski).

Nick Low, 1980

Nick graduated from the University of Adelaide in 1986 with First Class Honours in Chemical Engineering. He was awarded the Institute of Engineers Australia Award for Engineering and the Lokan Prize for Chemical Engineering. Following a two year break to chase the international tennis circuit, Nick returned to Adelaide and joined Dowell Schlumberger. During the next 21 years Nick held operational and engineering positions in Australasia, UK, France and USA. This included product development in their Global Engineering Centres in France and the USA, in collaboration with the Schlumberger Research Centre in Cambridge. Nick then worked for BP as a Well Construction and Cementing Engineering Advisor for their Global Exploration and Production Technology Group, in Algeria, Oman and Libya.

Since 2010 Nick has worked as a Project Manager and Senior Drilling Engineer for Vysus Group in Aberdeen Scotland. Nick has attained the Grade of Fellow with the Institution of Chemical Engineers.

His recent work in green energy and decommissioning is typical of the "technology refocus" with the current energy transition in the world today and aptly accommodated by the core chemical engineering and science principals attained during his time at university and PAC.

Christopher Miller, 1981

Chris studied medicine at the University of Adelaide and since graduation has worked in various medical specialisations including general practice, sexual health, health informatics and travel medicine. He developed an interest in the use of computers and the internet in medicine and gained additional qualifications in health informatics and the internet in health care and has worked in medical software and web development and consulting. Since 2010, Chris has refocussed on clinical medicine, with particular interest in skin cancer screening, diagnosis and management.

Wesley Phoa, 1982

Wesley graduated with Honours in Mathematics from ANU and then took up a scholarship to Trinity College, Cambridge, where he studied category theory and the mathematics of computing. After several years as a lecturer in the Department of Computer Science, University of NSW, Wesley worked for the Deutsche Bank in Australia in their fixed income division. He now lives in the USA where he works as a consultant to the finance sector.

Richard Moore, 1983

An ANU graduate with Honours in Pure Mathematics, Richard began his career in Sydney's finance sector, leading Equity Capital Markets for Citigroup before moving to Brisbane in 2000 to serve as CEO of the ASX-listed internet company Dark Blue Sea. Following the company's acquisition in 2010, Richard turned his focus to angel investing, founding MooCoo Ventures, which now manages the Brisbane Angels group. A driving force in the Australian startup ecosystem, he has been recognized as Australia's Most Active Angel Investor for several years running. Previously a Non-Executive Director for UniQuest, Richard continues to apply his expertise in mathematics and investment banking to lead deal screening and support high-growth technology ventures through the angel investment landscape.

Andrew Moore, 1984

Andrew completed a BSc and BEc at ANU before commencing a career in finance in Sydney. He went on to qualify as a Chartered Accountant and completed an MBA at INSEAD in France. Over a career spanning 30 years, including 8 years in Europe, he worked in various executive roles for PwC, Bankers Trust, General Electric and the Westpac Group. More recently, Andrew spent 7 years as the Chairman and CEO of a fintech start-up called Spaceship, a leading provider of investment, trading and superannuation products to younger Australians. Following the 2024 acquisition of Spaceship by eToro, a NASDAQ-listed trading platform company, Andrew is pursuing a career as a non-executive director. Current Board roles include RACQ, ASX-listed Helia Group and Spaceship Capital.

Nick Falkner, 1985

After completing a PhD in 2007, Nick is currently a Senior Lecturer in the School of Computer Science at the University of Adelaide and is also an Associate Dean for the Faculty of Engineering, Computer and Mathematical Science. He has been involved in a number of educational projects involving puzzle-based learning and flipping the classroom. The Computer Science Education Research group at Adelaide is currently developing resources to support the Digital Technologies component of the new National Curriculum, in conjunction with Google.

David Fotheringham, 1986

David completed an M. Sc. in Laser Physics at ANU in 1995 and undertook a Masters degree in Theology at the Melbourne College of Divinity (now the University of Divinity). After ministering in several Uniting Church congregations David has taken up the role of Moderator of the Uniting Church Synod of Victoria and Tasmania.

David Silver, 1987

David completed a degree in Computer Systems Engineering at Adelaide University in 1991. He then worked as a Research Engineer in the field of avionics with the Department of Science and Technology Organisation (DSTO), Salisbury, and now works as Systems Engineer for Integra Australia at Technology Park.

Chor Chen Goh, 1988

Chor completed Law at University of Adelaide.

Adam Hanieh, 1989

After studying engineering, Adam devoted himself to human rights. Since 1997 he has worked for several human right organizations, including the United Nations in Palestine. He is now the Research Coordinator of Defence for Children International/Palestine Section. This role includes documenting cases of human rights violations against Palestinian children and providing legal services to children who are held as political prisoners.

Samuel Whittle, 1990

Sam was awarded the Adelaide University Medal in the Health Science division on completion of his M.B., B.S. (Hons) degree. After completing his medical degree he undertook specialist training in rheumatology in Adelaide and the UK. He completed a masters degree in clinical epidemiology in 2010 and is now a consultant rheumatologist at the Queen Elizabeth Hospital. Sam combines clinical work with research: He is currently an adjunct senior research fellow at Monash University and co-founded the Australia and New Zealand Musculoskeletal Clinical Trials Network. In 2024 he commenced a two-year term as President of the Australian Rheumatology Association.

Kingsley Storer, 1991

Kingsley completed his B Med Sc (Hons) in 1997 and MB BS in 1998. After an internship at the Royal Adelaide Hospital he moved to Royal North Shore Hospital, Sydney. In 2007, he was awarded a PhD in Neurosurgery from the University of New South Wales for an investigation of the effects of high dose radiation on arteriovenous malformations within the brain. Since June 2007, he has lived in New York City where he is currently Assistant Professor in Anesthesiology at New York's Weill Cornell Medical College with a clinical anaesthetic practice and a research focus on how general anaesthetics cause unconsciousness.

Ben Gooden, 1992

Ben was awarded a B.Sc. (Honours) in physiology from the University of Adelaide in 1998. He then studied Medicine at the University of Sydney and completed his M.B., B.S. (Honours) degree in 2001. He researched the cause of spontaneous tendon rupture at the Raymond Purves Bone and Joint Research Laboratories and was awarded a Ph.D. from the University of Sydney in 2009. He resumed his clinical work and in 2010 became a Fellow of the Royal Australasian College of Surgeons. His post-fellowship training was at the Klinikum Emil von Behring in Berlin. He completed a Fellowship in Orthopaedic trauma, hip and knee arthroplasty at Royal Prince Alfred Hospital, Sydney. He now practices as an orthopaedic specialist at the Mater Private, Adventist and Hornsby Ku-ring-gai Hospitals in Sydney and Tamworth Rural Referral Hospital.

Andrew Newman, 1993

Andrew graduated with Honours in Mathematical and Computer Science from the University of Adelaide in 1996 focusing on game theory. After graduating Andrew worked as a management consultant at PA Consulting in Melbourne and completed a Graduate Diploma in Applied Finance and Investment from FINSIA. In 1999, Andrew joined what is now Macquarie Capital, the investment banking division of Macquarie Group. Andrew then returned to Adelaide and focuses on the infrastructure sector, and lead the Macquarie team on the successful bid for the New Royal Adelaide Hospital PPP in 2011.

Matthew McConnell, 1994

Matthew graduated in 2000 from the University of Adelaide with a M.B.,B.S. He went on to further his post-graduate studies and was awarded with a Masters in Public Health. He was a part-time Lecturer at the University of Adelaide's Medical School for six years before commencing advanced training in public health medicine with the Royal Australasian College of Physicians. Matthew became a Public Health Physician in early 2014 and is working in South Australia.

Shom Goel, 1995

Shom Goel graduated MBBS in 2003 from the University of Adelaide. He was awarded the prestigious Alumni University Medal for being ranked the most outstanding honours graduate of his year. Shom was ranked the top M.B.,B.S. student each year of his course and along the way he received 19 prizes and scholarships.

Ross Mullner, 1996

Having completed a Chemical Engineering Degree (Honours) at Adelaide University, Rossworked as a Process Technician at the Mobil Adelaide Refinery until its closure. He then joined Santos as a Senior Process Engineer, supporting various Gas Plant operations and projects around Australia.

Gwyn Morfey, 1997

Gwyn undertook a double degree in Law and Commerce, with a major in Computer Science, at Flinders University.

Tom Newman, 1998

Tom graduated in Commerce, University of Adelaide.

Mitchell Raeside, 1999

Dux of School, Mitchell began an accelerated science degree at Flinders University which he completed in 2001, winning the Bragg Medal for the best Physics student. Mitchell completed missionary work for his church in 2002-2003 in Taiwan and then undertook an MBBS (Hons) at Flinders University. He completed radiology specialist training in SA and then spent 12 months doing fellowship training in oncologic imaging at Memorial Sloan-Kettering Cancer Centre in New York City. He is currently the Managing Partner at Jones Radiology and a consultant radiologist at the Royal Adelaide Hospital.

Iain Murchland, 2000

Iain completed a Bachelor of Biotechnology (Hons) at the University of Adelaide, and commenced a PhD in the field of structure-based drug design in the Discipline of Biochemistry at the University of Adelaide.

Peter Mathews, 2001

Peter completed a degree in Engineering (IT and Telecommunications) with Mathematical and Computer Sciences at University of Adelaide.

Edward Heddle, 2002

Edward completed Science at University of Adelaide.

Mark Hosking, 2003

Mark holds a Bachelor of Laws and a Bachelor of Commerce from the University of Adelaide, and a Master of Law from the University of Cambridge. Mark currently practises as a barrister in Melbourne.

Chris Davies, 2004

Chris completed a Bachelor of Mathematical and Computer Sciences at the University of Adelaide, and Honours in Statistics for which he was awarded the Adelaide University Medal. After working at the Australian Bureau of Statistics and in the University of Adelaide School of Public Health, he completed a PhD in Statistics at the University of Adelaide. He is now a Senior Biostatistician at the Australia and New Zealand Dialysis and Transplant Registry based at the South Australian Health and Medical Research Institute.

George Evans, 2005

George graduated in 2011 from the University of Adelaide with an M.B.B.S. and was admitted as a Fellow of The Royal Australian and New Zealand College of Psychiatrists in 2020. He currently works as a general adult psychiatrist in Adelaide.

Paul Hosking, 2006

Paul completed a Bachelor of Medicine and a Bachelor of Surgery at the University of Adelaide in 2012. He was admitted as a Fellow of The Royal Australian and New Zealand College of Psychiatrists in 2020, and now works as a Child and Adolescent Psychiatrist in Adelaide.

Sam Lehman, 2007

Sam enrolled for a double degree in Health Sciences and Law, University of Adelaide.

Harry Crawford, 2008

Harry completed a Bachelor of Arts, majoring in Chinese Language, from the University of Adelaide, and worked for six months in Beijing.

Jerome Squires, 2009

Jerome is studying Law and Arts at the University of Adelaide.

Nicholas Burton, 2010

Nicholas graduated with a Bachelor's in Civil and Structural Engineering from the University of Adelaide and a Master's in Sustainable Design and Construction from Stanford University, specialising in earthquake-resilient building design. He currently works for Skidmore, Owings & Merrill in San Francisco.

Tien Chen 2011

Tien is currently undertaking the Doctor of Medicine (MD) degree at Griffith University, and hopes to become an internal medicine physician. In 2012 he graduated from PAC as joint Dux of the College, and in 2014 graduated from Griffith University with a Bachelor of Medical Science (BMedSc). Tien also holds an Associate Diploma in Music, Australia (AMusA) and over the summer, was the inaugural Summer Scholarship holder at the South Australian Health and Medical Research Institute (SAHMRI).

Henry Bui, Co-Editor 2012

Henry is studying Medicine at University of New South Wales, in Sydney.

Theo Squires, Co -Editor 2012

Theo is studying a double degree in Finance and Mathematics with Computer Science at the University of Adelaide.

Isuru Dissanyake, 2013

Isuru studied Bachelor of Science (Advanced) at University of Adelaide, recently completing it with a major in Chemistry. He has recently completed First Class Honours in Chemistry and in 2019, embarked on what was a long term goal of his of studying a PhD in orgainc synthetic chemistry. Isuru was acknowledged in an Australia Day ceremony as a "Young Citizen of Australia 2015."

Timothy Hobbs, 2014

Timothy Hobbs graduated from the Australian National University with a Bachelor of Laws [Honours] and a Bachelor of International Security Studies in 2020. Since graduating, Tim has worked with the National Security College and as an in-house legal adviser at a space-tech start-up. He's currently working as an adviser to a South Australian Senator.

Yu Le Kong-Lim, 2015

Yu Le Kong-Lim completed his IB Diploma and was a College Prefect in his final year of senior schooling. He was heavily involved in the School music program and a keen debater. On leaving school he studied Law and International Studies at University.

Eddie Han, 2016-17

Eddie graduated from the IB Diploma Program in 2017 and was the Chief Editor of the Science Journal in his last two years of senior schooling. He is currently studying Computer Engineering at New York University – Abu Dhabi.

Denny Han, 2018

Denny studied the IB Diploma in 2018-19 and after contributing to the Journal Committee for several years was Chief Editor in 2018. He is currently studying at New York University – Abu Dhabi.

Seran Perera, 2019

Seran graduated from SACE in 2019 after working as the Chief Editor during the Science Journal's 75th edition. He is currently studying Medicine at the University of Adelaide and is excited to explore the role of science in global health.

Joshua Lesicar, 2020

Josh studied a Bachelor of Marine Science at James Cook University (JCU), graduating as valedictorian in 2024 for both his degree and the College of Science and Engineering. He then completed an Honours degree in Marine Biology at JCU, during which he participated in the Denman Marine Voyage, a scientific expedition to the fastest-receding glacier in East Antarctica (2025). In recognition of his academic achievements and co-curricular contributions, Josh was awarded the prestigious Rhodes Scholarship to undertake a DPhil in Earth Sciences at the University of Oxford (2026). His research will investigate phytoplankton assemblages, which form the foundation of marine food webs and play a vital role in regulating Earth's climate through the global carbon cycle.

Dinan Perera, 2021

Dinan enjoyed several years on the Journal Committee before his involvement culminated in him being Chief Editor in 2021. After graduating from the SACE at the end of that year, Dinan was accepted into Medicine and the University of Adelaide.

Hoon Kang, 2022

Hoon was accepted into Medicine at the University of Adelaide. With a long road ahead of him he is unsure as to what area he will specialise in at this early stage. Hoon is also interested in the research aspect of medicine and is looking forward to exploring opportunities in this area as they present. He has remained in touch with the Prince Alfred community by helping with tutoring of our boys.

Winston Huang, 2023

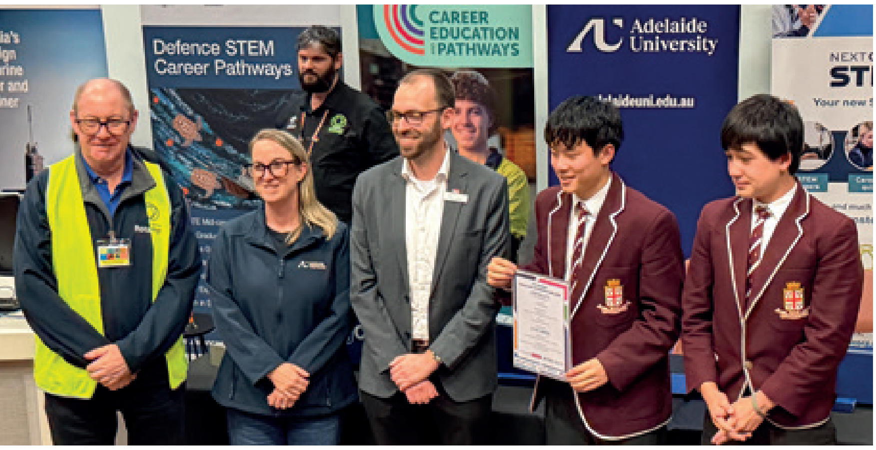
Winston is currently studying a Bachelor of Biomedicine at the University of Melbourne and aiming to become a Doctor of Dental Medicine.

Caleb Tang, 2024

Caleb graduated as the dux of the IB Diploma Program in 2024 alongside winning the Oliphant Trophy that year. He served on the journal committee for many years before becoming chief editor in the journals eightieth edition. He has since accepted a place to study medicine at the University of Adelaide.

Aryan Parwal, 2025

After studying all three sciences in Year 12 and serving on the Science Journal committee for several years, culminating in his role as Chief Editor, Aryan is now studying a Bachelor of Science, majoring in Physiology at the University of Melbourne. He will commence the Doctor of Medicine pathway in 2029, and looks forward to blending his passion for the sciences with a future in clinical medicine.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Contents

Bugs, mums and bubs: how the reproductive tract microbiome shapes women's and early life health

Professor David A. MacIntyre, PhD, FRSB
Director, Robinson Research Institute,
Adelaide University

Guest article

Introduction

The human body is colonised by a vast number of microbes that shape health and disease states. It is estimated that around 38 trillion bacteria, viruses and fungi reside in and on our bodies, slightly outnumbering the total number of human cells. That is approximately 200-300 times more than the numbers of stars in the Milky Way Galaxy. This collection of microbes and the genetic information they carry is called the microbiome. The amount of genetic information contained within these bugs is immense. The human genome contains around 20,000 genes, while the collective genomes of all the different types of microbes within an individual are estimated to be as many as 8 million genes. This means that for every human gene, there are more than 300 different microbial genes. Biologically speaking, you are a minority shareholder in your own body.

The microbes colonising the human body are not simply bystanders. Nor are they unwelcome invaders, as often and unfairly described. Instead, microbes have co-evolved with humans to develop a mutualistic relationship - we provide a warm, nutrient-rich home, and in return, the resident, commensal microbes help with energy metabolism, training the immune system in early life, and with fighting off harmful, pathogenic microbes that can cause infections.

While much attention over the last couple of decades has focused on studying the gut microbiome, there is increasing awareness of the importance of the lower female reproductive tract microbiome. The vagina and cervix (the neck of the womb) host their own distinct collection of microorganisms. Understanding this hidden ecosystem and how it impacts fertility, pregnancy, infection risk, and even the health of newborn babies has been the focus of my research for more than 15 years. In this article, we will look at how advances in DNA sequencing have allowed scientists to catalogue these microbial communities in detail, revealing patterns that were invisible to earlier techniques. The result is a rapidly growing field that connects basic microbiology to some of the most pressing challenges in women's health, from infertility to premature birth.

A brief history of studying microbes

For most of the 20th century, our understanding of microbes was limited by a simple constraint: to study a microorganism, you generally had to grow it or examine it with a microscope. Scientists would typically take a sample (e.g. soil, water, or a swab from a patient) and try to culture its microbes on a nutrient-rich medium in a petri dish. Once enough bacteria had multiplied, colonies large enough to see would form, which could then be counted and examined. This approach worked well for a minority of microbes, those that thrive under lab conditions. However most microbial species, particularly those that colonise our bodies, refuse to grow outside their natural habitat. Instead, they need very specific nutritional and chemical conditions, particular temperatures, or even the presence of other microbes to survive and grow. The revolution came with a technique called next-generation sequencing. Instead of culturing organisms, researchers could extract all the microbial DNA in a sample, sequence it and read the complex genetic codes contained within, then compare these against databases to identify which microbes are present and what genes they carry. In this way, microbial genes can be used like barcodes or fingerprints, providing enough information to match them to their owner. This approach revealed an entirely new, far more complex microbial universe that had been previously invisible to science.

In 2007, the United States National Institutes of Health launched the Human Microbiome Project, an ambitious initiative that set out to characterise the microbial communities across multiple body sites of 'healthy' individuals by applying these new sequencing technologies. A key discovery of the project was that there is enormous variation in microbiome composition across body sites (Figure 1). For example, the gut was found to be full of bacterial species that can be grouped into phyla called Actinobacteria and Proteobacteria, whereas the vagina was found to overwhelmingly contain Firmicutes. More specifically, most healthy, reproductive aged women are colonised by a species of bacteria called Lactobacillus.

Subsequent studies showed that there are four main species of Lactobacillus that most commonly colonise the reproductive tract: *Lactobacillus crispatus*; *Lactobacillus iners; Lactobacillus gasseri*; and *Lactobacillus jensenii.* These species are closely related, but have different functions and properties that are still to be uncovered.

The reproductive tract microbiome from birth to menopause

The amounts and types of microbes in the reproductive tract are not fixed for life. Instead, the composition of the microbiome transforms throughout a woman's life, largely driven by the hormone estrogen. Rising estrogen at puberty helps drive the production of a sugar called glycogen

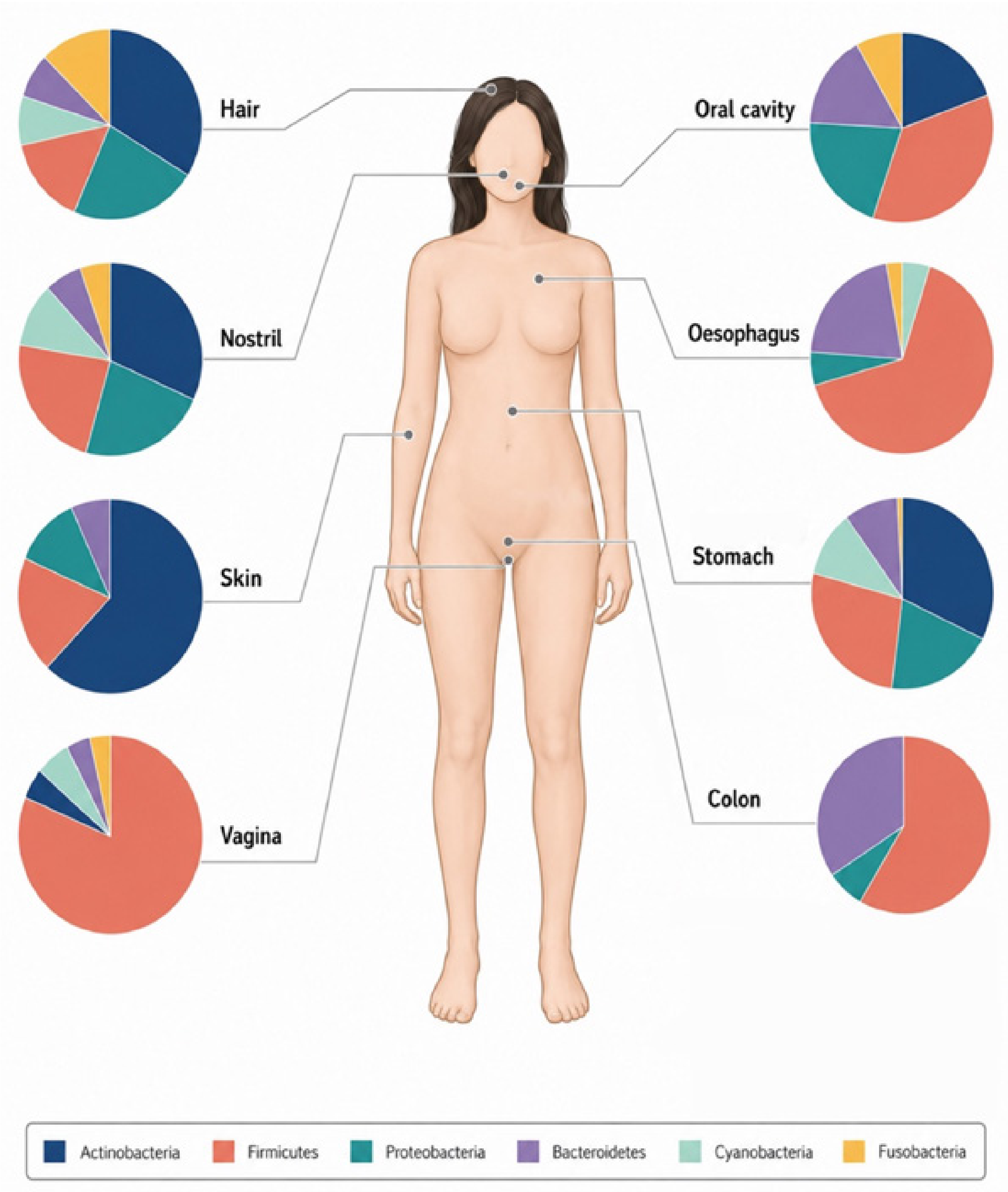

Figure 1: Body site-specific composition of the healthy human microbiome. Relative abundance of the major bacterial phyla across distinct body sites in healthy adults, illustrating the characteristic microbial community composition associated with each anatomical niche. Pie charts represent the mean relative abundance of the dominant bacterial phyla (Actinobacteria, Firmicutes, Proteobacteria, Bacteroidetes, Cyanobacteria and Fusobacteria). The figure highlights the marked differences in microbial composition between skin, respiratory, gastrointestinal and vaginal environments. Figure modified from Cho and Blaser, 2012[1].

production in the lining of the lower reproductive tract, which favours the growth and colonisation of Lactobacillus. During the reproductive years, monthly hormonal swings across the menstrual cycle cause natural, minor fluctuations in the balance of these bacteria. Pregnancy brings the most dramatic hormonal shift a woman will experience during her lifetime. The placenta produces very high levels of estrogen, which pushes the vaginal microbiome toward strong Lactobacillus dominance. After the baby is delivered, estrogen levels dramatically fall, and Lactobacillus species can be lost from the microbiome. In some women, it can take more than a year for these species to return. At menopause, estrogen levels decline permanently, leading to decreases levels of glycogen and loss of Lactobacillus species.

Lactobacillus: defenders of reproductive health

Co-evolution of microbes and humans has led to close mutualistic relationships forming. In the case of Lactobacillus, their feeding on glycogen and other sugars in the lower reproductive tract helps them thrive and colonise. In return, they produce lactic acid as a by-product. This acid keeps the cervix and vagina at a low pH of roughly 3.8 to 4.5. While Lactobacillus can thrive in this acidic environment, many disease-causing microbes cannot. Lactic acid also helps calm inflammation and supports the integrity of the protective mucosal barrier. Lactobacillus species add a second line of defence by producing bacteriocins, which are small antimicrobial molecules that directly suppress the growth of competing - and possibly harmful - bacteria, viruses, and fungi.

Not all Lactobacillus species offer equal protection. *Lactobacillus iners,* for example, often coexists alongside disease-associated bacteria rather than excluding them. This is likely because it may depend on its bacterial neighbours for nutrients it cannot produce itself. When Lactobacillus species are pushed out of the reproductive tract altogether, the resulting high-diversity communities often contain pathogenic microbes that can cause infections and disease. There are many factors that can cause this shift in the composition of the microbiome including menstruation, hormonal changes, hygiene practices and antibiotic use. If interested, you can

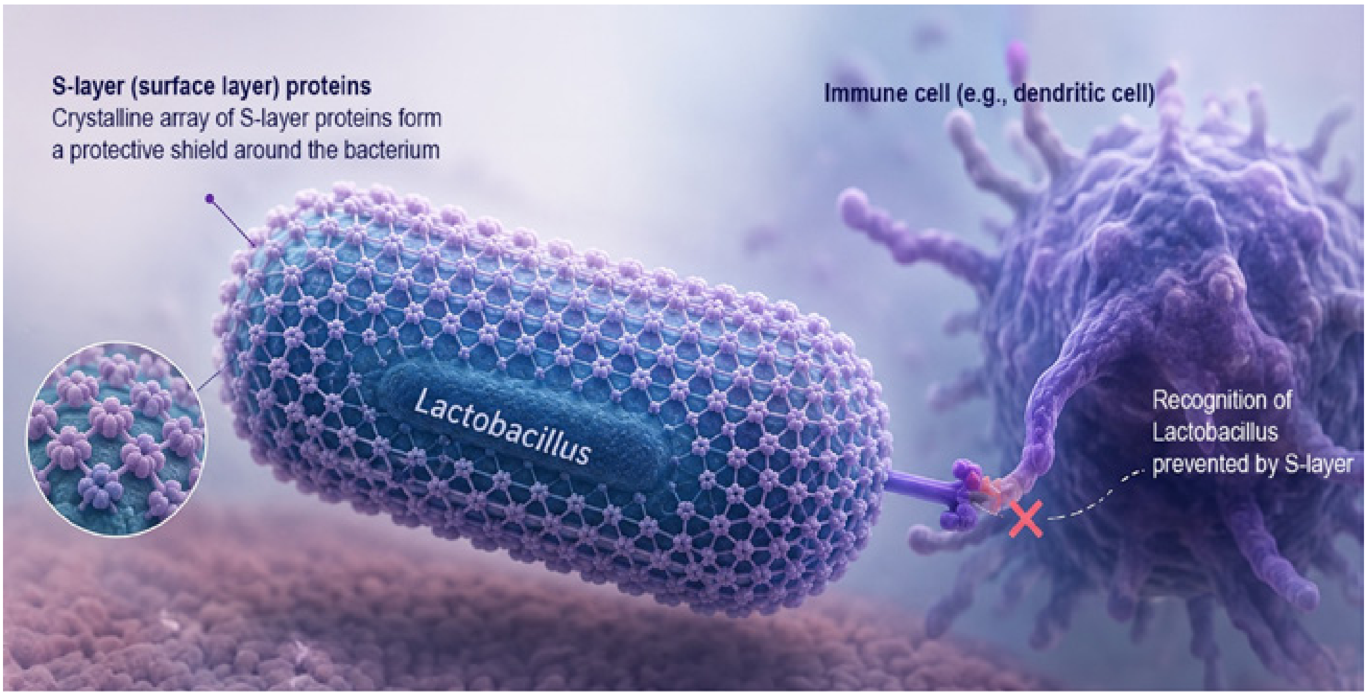

Figure 2: Interpretation of how S-layers on the surface of Lactobacillus prevent them from being detected and removed from immune cells.

learn more about detailed mechanisms involved in colonisation of the reproductive tract microbiome in a review article we have recently published[2].

Microbial cross-talk with the immune system

Microbes in the reproductive tract are constantly communicating between themselves and with host cells, particularly immune cells. The cells lining the lower reproductive tract, called the epithelial barrier, constantly sample microbes in their vicinity and adjust their behaviour and responses. A Lactobacillus-dominated microbiome helps keep local immune activity calm, producing low levels of inflammatory signalling molecules called cytokines. If pathogens start to colonise the reproductive tract, immune cells detect their presence and activate an immune response, which leads to inflammation and eventually the clearance of the infecting pathogen. Recently, our laboratory discovered that one of the ways in which Lactobacillus avoid activating the immune system is by producing a protein 'cloak' around the outside of their cell walls, made up of proteins called "S-layer" proteins[3]. These proteins create a shield between the bacteria and immune cells preventing them from recognising and killing them (Figure 2).

The microbiome and pregnancy

Inflammation is a fundamental component of reproductive tract function, particularly during conception and pregnancy. Following fertilisation, a carefully orchestrated inflammatory response within the lining of the uterus (called the endometrium) helps to create a receptive tissue environment that supports implantation of the embryo. Similar immune-mediated processes are essential during placental development, where controlled inflammation helps the placenta embed well into the uterus and provide the developing fetus with oxygen, hormones and nutrients, while removing waste products. At the end of pregnancy, labour is triggered by the activation of immune and inflammatory pathways throughout the reproductive tract. In the cervix, inflammation is key to softening and 'ripening', which allows the baby's head to pass through the birth canal during labour. Inflammation also leads to the rupture of the amniotic sac before birth. Finally, inflammation plays a critical role in causing uterine contractions to start. If these immune or inflammatory processes are triggered too soon, this can lead to adverse pregnancy outcomes like early pregnancy loss or premature birth. Consistent with this, we and others have shown that a reproductive tract microbiome dominated by Lactobacillus, particularly *Lactobacillus crispatus,* helps support healthy pregnancy outcomes.

Researchers are now investigating whether testing a pregnant woman's microbiome early on could help identify those at higher risk of preterm birth, well before any symptoms appear, so that preventive treatment could begin sooner. This kind of early-warning approach is still experimental, but it illustrates how basic microbiology research can translate directly into new tools for clinical care.

Passing the microbiome to the next generation

The importance of the reproductive tract microbiome may also have longer lasting consequences for the newborn baby. For most babies, the very first microbes they encounter are at the time of delivery as they pass through their mother's birth canal. These microbes, and those they receive during breast feeding, help establish their gut microbiome. The early communities of microbes in the newborn's gut play an important role in helping digest food, training the immune system, and setting up early life metabolic pathways. A baby delivered by C-section is never exposed to those birth-canal microbes. Scientists think this may explain some of the associations reported between C-section delivery and the higher risk of conditions that arise in childhood including asthma, allergies, and obesity. This is an area of much current research activity. If proven it may offer a new way to prevent the development of such childhood diseases through modification of the early life microbiome.

Conclusions

The microbes that colonise the human body, including the reproductive tract are not passive passengers but rather are active participants in reproductive health, from puberty through pregnancy and into the next generation. Cutting edge methods are increasingly enabling scientists to understand the types of bacteria present in our microbiomes, how they communicate with our immune system and defend against disease, and how they shape reproductive health. The reproductive tract microbiome is a dynamic, hormonally responsive ecosystem with consequences that extend well beyond the individual, influencing fertility, pregnancy outcomes, and the earliest microbial foundations of a newborn's lifelong health. As this research matures, the challenge ahead lies in translating these discoveries into practical tools that can lead to better health outcomes for mums and bubs.

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Glossary

C-section: Caesarean section: delivery of a baby through surgical incisions made in the belly and uterus.

Commensal microbes: Types of microbes residing at different body sites without causing any harm to the host.

Microbiome: the entire habitat, including the microorganisms (bacteria, fungi, archaea, and viruses), their genomes (i.e., genes), and the surrounding environmental conditions.

Pathogenic microbes: Types of microbes that causes disease to the host.

Phyla: high-level grouping used to sort and organise bacteria based on their shared ancestry and genetic makeup.

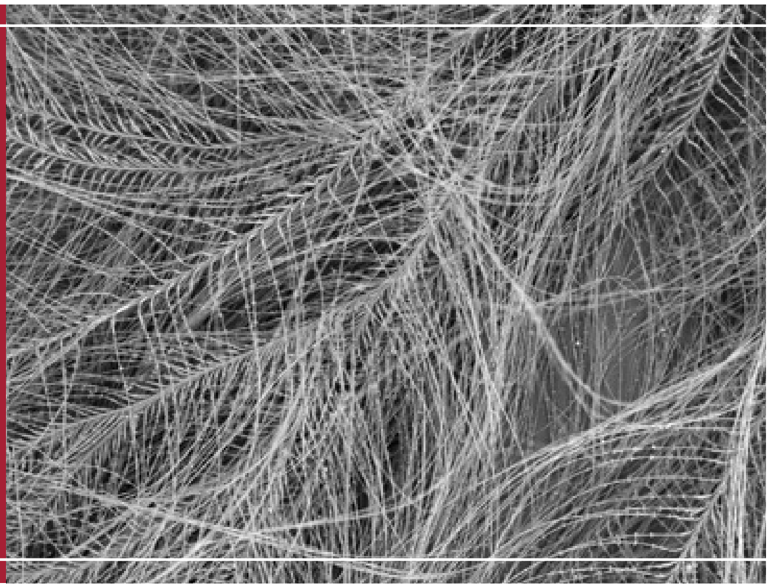
Placenta: a temporary organ made by the baby that grows in the uterus during pregnancy. It connects to the baby through the umbilical cord and supplies food, oxygen, and hormones while removing waste.

Biography

David MacIntyre is Professor of Reproductive Systems Medicine and Director of the Robinson Research Institute at Adelaide University, which is dedicated to tackling the most pressing reproductive health issues by undertaking cutting-edge research to improve fertility and pregnancy outcomes, as well as fostering early childhood health in Australia and across the globe. He received his PhD in Reproductive Medicine at the University of Newcastle, Australia in 2007, before undertaking post-doctoral training at the Centro de Investigacion Principe Felipe in Valencia, Spain where he was awarded the Marie Curie International Incoming Fellowship. In 2010 he moved to Imperial College London, where in 2013, he received the prestigious UK Medical Research Council Career Development Award. In 2018, he became Co-Director of the March of Dimes Prematurity Research Centre at Imperial College, a position he still holds. He has established an internationally recognised research program focused on understanding how the microbiome influences reproductive health outcomes, particularly in the context of pregnancy. In recognition of his work, he has received several awards including the 2024 J. Christian Herr award from the American Society for Reproductive Immunology for outstanding achievements in basic or applied research in reproductive immunology, and the 2026 Distinguished Scientist Award from the Society for Reproductive Investigation. In July 2025, was elected as a Fellow of the Royal Society of Biology. Find out more about the Robinson Research Institute via https://adelaide.edu.au/research/robinson-research-institute/

What is this?

Find out what the scanning electron microscope sees on page 73.



High-throughput plant phenotyping

Words by Aaron Liu (Year 10)

Agriculture

Introduction

In the last decade, technologies in agriculture have been used to rapidly increase the efficiency of pre-existing methods. This can be seen in technologies such as precision drone usage, combine harvester for harvesting crops, and high-throughput plant phenotyping. This article will explore how plant phenotyping works and its applications and limitations.

Background

Plant phenomics is the study of plant traits. The study is an interdisciplinary collaboration merging biology, chemistry, engineering and data science together. Traits that are tracked include height, growth speed, salt tolerance, flowering time, yield, and disease tolerance. The recording and analysis of this data is known as plant phenotyping. The concept of plant phenotyping has existed since humans began farming, but it was a tedious and labour-heavy process. It involved taking measurements by hand and could also be very invasive. Modern day plant phenomics uses high-throughput plant phenotyping (HTP), which is a large-scale, non-invasive and heavily automated process used to efficiently identify desirable phenotypes.

HTP either takes place outside in the plant's natural environment (field phenotyping), or indoors (controlled-environment phenotyping) for precise research. The process begins when sensors, mounted onto an autonomous platform such as a drone or rail system, collect data about the plants (Figure 1). There are 6 main types of sensors: RGB, multispectral, hyperspectral, thermal, LiDAR, and fluorescence. A RGB camera perceives only red, green, and blue bands (regions of the electromagnetic spectrum), replicating what the human eye can perceive. It is used to measure plant size, growth, and colour changes. Multispectral imaging covers 3 to 10 bands and is useful for estimating biomass, yield and general plant health. Hyperspectral imaging is more expensive and data-heavy which is used for extremely detailed analysis of biochemistry. It collects data about chlorophyll content, nitrogen levels, water content, and early-stage disease detection. Thermal sensors can perceive changes in the surface temperature of plants, used to assess plant stress because plant heats up when under stress. LiDAR is a process where laser pulses map out a 3D model of the plants which is useful for measuring height and canopy (stems, leaves, flowers) structure. Finally, fluorescence sensors are used to measure the light emitted by chlorophyll during photosynthesis which is used to assess photosynthetic efficiency. These sensors are

Figure 1: Automated precision phenotyping greenhouse

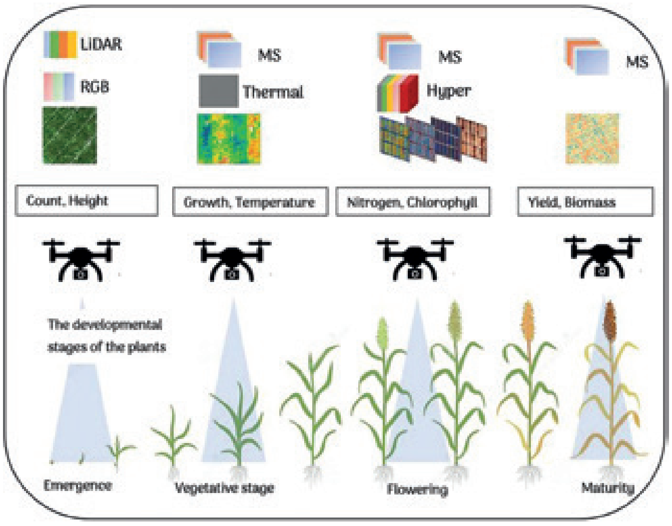


Figure 2: Schematic overview of the different ways to extract spectral information from plants

crucial because they can perceive things that would otherwise be impossible for humans to measure by hand. They work in conjunction because each has unique jobs during various developmental stages of a plant (Figure 2).

This data is then stored and sorted by time (temporal data) and location (spatial data) to map out plant growth and changes over time in different areas. This raw data is then interpreted by machine vision (AI) which turns it into useable, meaningful biological data. For example, raw data is an image of a leaf, with soil behind it, consisting of millions of pixels, all with different temperature values. When fed through machine vision, the useful pixels of the leaves are filtered through, while the background and sensor errors are removed. This leaves just the leaf and an accurate thermal map (Figure 3).

Applications and limitations of high-throughput plant phenotyping

As of 2026, the world population is over 8.3 billion and this number is growing steadily every year. Of these, over 2.3 billion suffer from moderate to severe food insecurity. Historically, world hunger has always been a crisis faced by humans, but it has been compounded by an emerging threat-climate change. A study showed that rising temperatures attributed to climate change have lowered corn, barley, and wheat yield by up to 13%. To compensate for the rising demand of food caused by climate change, agriculture must find a way to adapt.

Plant phenotyping provides a way for agriculture to become more accessible, efficient, and therefore cheaper. Plant breeders hire phenomics researchers to find the best genotype for their specific situation. Plant breeders then sell the ideal seeds to the farmers, who are able to grow crops. For example, plant breeders may need to find a crop that can withstand high heat. Normally, finding the best plant would take months of manual breeding, but with HTP, thousands of plants can be screened extremely quickly, and researchers can definitively find the plants with the most drought-resistant genotypes. Another example of how plant phenotyping can cut down costs, is that by finding the most bug-resistant crop, farmers can save money on pesticides. Plants that are resistant to heat and drought can be planted in areas that would otherwise be difficult to farm (Figure 4).

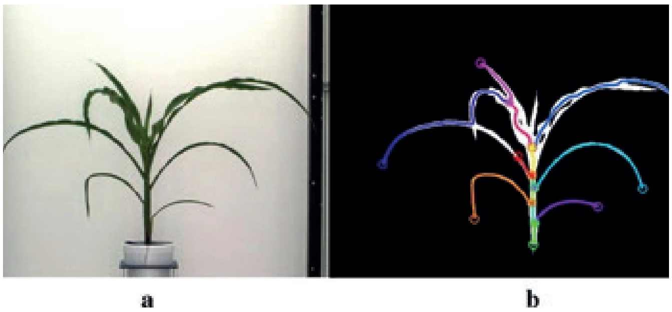


Figure 3: Thermal map of a plant

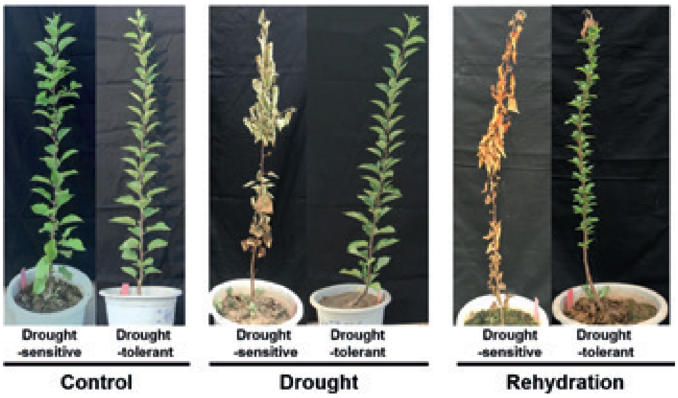


Figure 4: Drought resistant plants

However, HTP comes with its limitations. The sensors collect enormous datasets which are exceedingly slow to process. One image derived from hyperspectral imaging alone can take up more than 50 MB which means that terabytes of data are produced very quickly. This puts a strain on storage capacity and processing time. Furthermore, HTP equipment is extremely expensive. Hyperspectral, LiDAR, and thermal sensors, as well as the robotic platforms and controlling the greenhouse environment cost hundreds of thousands of dollars. This makes it inaccessible for small-scale labs and farms. These are the main problems that HTP faces today.

In the future, HTP will be expanded and made even more efficient. 'EMPHASIS' is an international project that aims to create 'European Infrastructure for Multiscale Plant Phenotyping and Simulation for Food Security in a Changing Climate'. Nations worldwide are adopting plant phenotyping technologies. In Australia, 9 plant phenomics facilities have merged to create Australian Plant Phenomics Network demonstrating the collaborative effort and growth (Figure 5). It is simultaneously becoming more accessible as the technology becomes cheaper. As the prices of sensors and AI models decrease, the goal is to make phenotyping common, even for small farms. The accuracy of phenotyping will increase as machine vision models will become better at analysing data. For example, an AI will go from detecting plant stress in retrospect to predicting imminent plant stress.

Conclusion

In a time where the global population is growing while the conditions for crops are worsening due to climate change, ensuring food security has never been more important. High-throughput plant phenotyping is the key as it turns what used

Figure 5: APPN

to be a slow and laborious process into an autonomous and accurate one. However, the excessive data usage and short-term costs limit its accessibility. But plant phenotyping is a rapidly expanding technology, so its future may bring humanity one step closer to reducing global food insecurity.

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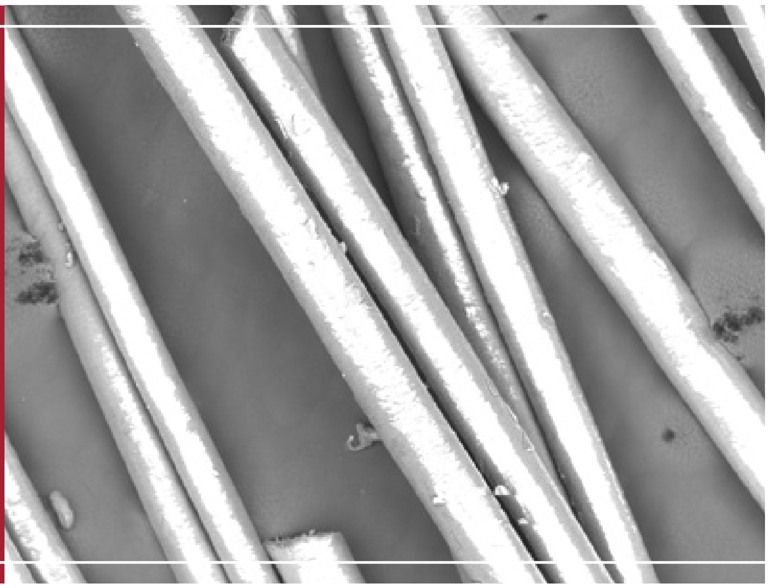

What applications and limitations do AI powered climate control systems have in controlled environment agriculture (CEA)?

Words by Clynton Vuong (Year 10)

Agriculture

Introduction

Agriculture is a crucial part of our society. However, agriculture has been affected by global warming and a growing population. The number of people experiencing extreme food insecurity has increased more than 9 times since 2016. AI powered climate control systems in controlled environment agriculture (CEA) have been employed to reduce the impact of climate change on agriculture. AI climate control in CEA and its applications and limitations of this technology in agriculture will be explored.

Background

The first step in AI climate control is data collection. A network of sensors is placed around the CEA facility to measure various factors. Temperature is measured using resistance temperature detectors (RTD). When temperatures increase resistance increases as demonstrated in Table 1.

This is because when particles are heated, they vibrate more rapidly causing more collisions between particles and electrons therefore increasing the resistance. Humidity is also a key factor in plant growth which is measured using a hygrometer. The hygrometer contains two metal plates separated by an insulator. The insulator absorbs water vapour in the air which

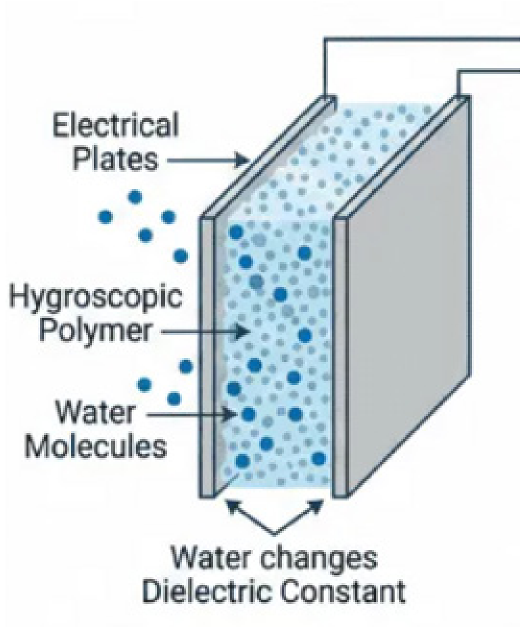

Figure 1: Hygrometer

increases the insulator's capacitance (the ability to store more of an electrical charge as water has a high capacitance). A voltage is constantly being sent between the two plates allowing the capacitance to be measured by a sensor.

The second step in AI climate control is the decision making. The AI uses a network of algorithms such as model predictive control (MPC). MPC estimates the condition of the plant and runs a series of simulations to make a prediction as to which simulation has the best outcome for the plant and for energy efficiency. Using this, the AI adjusts the temperature and humidity. Deep reinforcement learning (DRL) is also utilised as it can simulate factors such as external temperature, humidity, light etc.

The final step is the AI altering the climate. Temperature is controlled in CEA facilities by heating, ventilation and air conditioning units (HVAC). The air conditioner works by taking the warm air from the environment, running it over coils which have a cold refrigerant and then blowing it back into the room through a fan. This process is repeated until the desired temperature is reached. The heating unit uses a similar method, as it takes cold air into the unit, where the air is run over a warm surface instead.

Applications and limitation of AI climate control in CEA

One significant application of the AI climate control in CEA facilities is its ability to detect and adapt the environmental factors. Previously temperature and humidity in a CEA facility stayed at a fixed level or had to be manually changed, this

0°C	Ohms
0	100.00
10	103.90
20	107.79
30	111.67
40	115.54
50	119.40
60	123.24
70	127.07
80	130.89
90	134.70
100	138.50

Table 1: resistance increases as temperature increases.

caused crop growth and health to not be optimised. However, with AI climate control in CEA facilities, net profits were increased by 27.8%. Another significant application of AI is its ability to optimise energy consumption. Energy expense on climate control contributes to over 40% of farmers budgets in CEA facilities. However, with the use of AI climate control a 25% reduction in energy usage can be seen. This is achieved through the MPC and DRL systems constantly running simulations to optimise energy consumption whilst considering external factors such as light and temperature. Furthermore, by decreasing the amount of energy required to run the facilities and increasing crop output, this system allows for reliable food production in CEA in extreme environments such as deserts or arctic.

One limitation of AI climate control in CEA facilities is its resource consumption. In order to set up a CEA facility run by AI climate control, advanced technology and infrastructure are required. Therefore, starting a CEA facility run by AI climate control costs about $420 to $2000 per square meter. The price per square meter increases as the total amount of square meters decreases. As a result, the viability of AI climate control in CEA under harsh circumstances is diminished. Furthermore, although AI can reduce energy costs, electricity still makes up at least 30% of the CEA facilities expenses. Therefore, in the short-term farmers would be losing money by implementing this system. A CEA facility of 30,000 square meters costs approximately 3 million dollars per year to run without AI climate control. With it, it saves approximately 7 hundred thousand dollars per year. Assuming implementing the AI system costs the minimum of $420 per square meter, it will take 18 years for the farmer to recoup their investment. Thus, AI climate control in CEA is only practical in larger scale facilities.

Conclusion

AI powered climate control systems in agriculture present possible solutions to the growing food insecurity, optimising crop growth and energy consumption by applying sensors, algorithms and systems to regulate the environment. However, there are still significant limitations to this technology such as its cost. Therefore, whilst AI climate control in CEA has proven it has the capability to be effective, significant advancements in efficiencies must be made to allow more frequent use, particularly in regions where financial challenges will limit its widespread application. Therefore, whilst AI climate control in CEA has proven it has the capability to be effective, significant advancements in efficiencies must be made to allow more frequent use, particularly in regions where financial challenges will limit its widespread application.

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Cultivating tomorrow

Words by Josh Nguyen (Year 8)

Agriculture

Before agriculture, we humans began as lifelong hunter-gatherers. This limited population size and created pressure for communities to follow seasonal food sources constantly. 12,000 years ago, the first agricultural revolution (the Neolithic revolution) began in the Middle East. We then adapted to growing wheat and barley, domesticating animals such as sheep and goats. This shift changed the course of our very existence. This transformation allowed people to settle in one place instead of constantly looking for seasonal resources. The surplus of food sparked labour specialisation leading to many academic fundamentals such as writing and math. It also gave way to other ideas such as architecture or centralised governments.

For generations, farming relied entirely on human muscle and animal labour. That changed drastically during the Industrial Revolution when inventions like steam-powered tractors massively reduced the manual work needed to run large fields. It wasn't just about the machinery though. Since tractors could do the work of dozens of people, millions of farm workers moved into cities for factory jobs which sped up urbanisation. At the same time, factories started mass-producing new tools and synthetic fertilisers. This shift transformed farming from a small-scale struggle for survival into a commercial industry capable of feeding massive populations.

Not only does agriculture fill our stomachs and supermarket shelves, it also drives our economic stability, public health and geopolitics.

In many developing nations, agriculture helps employ over half of the national workforce and is a primary driver of the global economy. Looking further than the farming fields, crops are being transported at a mass rate and through a global chain of growing, processing, packaging, shipping and finally in the supermarkets. Since this system depends on each other, it can become fragile which means that small breakdowns can lead into global emergencies. If a drought or shipping delay were to occur right this second, this would lead to the inflation rise of groceries and make it harder for families to support themselves.

Affordable food supplies are directly tied to national security as governments lose legitimacy when citizens face inflation on basic staples. Historical analysis shows that agricultural shortages and price spikes regularly trigger political unrest, particularly in urban areas which are reliant on commercial food retail. For example, the 2011 Arab Spring uprisings were largely fuelled by droughts in Russia and Ukraine that doubled

Figure 1: Automated agriculture

North African bread prices. For nations that rely deeply on imports, this creates a major vulnerability to foreign conflicts and trade bans. Consequently, modern state strategies prioritise secure trade agreements and the acquisition of foreign arable land to protect sovereign food pipelines.

Modern farming has helped save millions from starving but the government's focus on crops such as wheat, corn and soy has altered global diets. Governments focus on making these items cheap, which makes them overlook the problem of obesity, which becomes an even bigger problem than starvation. These families can afford these products with high levels of calories, but they remain unhealthy, with nutritious food becoming a luxury that some can't buy.

Agriculture is under intense pressure from the change into unexpected weather patterns, global crisis and society.

Climate change has become an immediate threat to our global food security due to the rise in temperature and the unreliable weather patterns that beset us. Farmers now face extreme weather like severe droughts, major floods, and unseasonal floods, which can eradicate harvest in a matter of hours. Agriculture consumes nearly 70 per cent of the world's accessible freshwater, which concerns society's food chain because of the crisis and severe water scarcity. Our underground water supplies are running dry and our mountainous glaciers are melting drastically. This loss of water impacts major crop-growing areas such as California. Furthermore, our winters aren't cold enough to kill off harmful insects. Over the last 10 years, our winters have became warmer by an increment of 1.0 °C. Even though this may seem insignificant, this is a global emergency. This small yet dangerous increase represents a massive amount of heat being trapped in our atmosphere. Hence, it causes destructive pests to get into the food chain and destroy our crops.

Almost 186 countries rely on imported produce. Since everything we buy is so globally connected, this problem creates a massive food crisis, leaving at least 20-50 countries affected when a war breaks out. Consider the war happening right now between Ukraine and Russia. Since both countries supply 1/3 of the world's wheat and fertiliser, these prices spiked to new heights since the shipping routes were blocked in the Black Sea. This overwhelmed vulnerable and undeveloped countries that needed these imports to survive. To add insult to injury, countries become selfish and ban food exports to protect their own people, making the prices skyrocket even higher and making these global shortages way worse for everyone else.

By 2050, Earth's population will hit a new record, nearly 10 billion people. This means that we need to grow an extra 70 per cent to keep up with increasing population. Scientists predict that as we hit this record, our population will start to decline due to the scarcity of food around the world. The big problem we have is urban sprawl, where our cities expand constantly and take over the surrounding area. Because of this expansion, they end up paving over the road, covering up our fertile farmland to build houses and roads. This means farmers must move out into places with possibly worse soil. They must use more artificial fertiliser and water just to get their crops to grow. On top of this growing problem, pesticides are heavily used which can wipe out bees and insects, creating a massive pollen crisis.

To survive the 21st century, farming must evolve from one that exploits nature to one that collaborates with each other, which is why society should push for a new way called sustainable intensification, which basically grows more food while keeping our environmental impact to a minimum.

One path we can take is regenerative agriculture. We can plant cover crops and rotate across fields, which helps fix the soil and traps nutrients in the ground. Another strategy we can use is environmental agriculture which includes using LED lights and water to grow without soil. This would help cut the water use by over 90 per cent and completely remove any weather risk. Additionally, scientists are making massive breakthroughs in alternative proteins like plant-based meats and precision fermentation which can replace regular meat and take a ton of pressure off the massive amounts of land we currently use on livestock.

Ultimately, agriculture isn't just about planting simple seeds into the soil and letting them grow. It is the backbone of society. We stand at a crossroad where the methods we once used many many years back have led to political unrest, climate disasters, and water scarcity. If we want to have a chance of feeding our surplus population as we hit new numbers in the years to come, we can't stay with our old methods and grow more. Instead, we must grow smarter. By shifting to sustainable intensification, using precision technology, and working with nature rather than exploiting it, humanity can protect its food security and maintain peace.

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Is the acceptance of robotic dairies influenced by economic and social considerations?

Words by Lachlan Logan (Year 10)

Agriculture

Introduction

Agriculture constitutes a large amount of the Australian industry, providing $80.2 billion of goods and services exports per year, 2.2% of Australia's GDP, and 2.1% of national employment. With an ever-growing population to feed, the industry is constantly growing and looking for new technologies and more efficient ways to increase yield. With 7% of all cows in Australia being dairy cows , robotic dairies are an extremely efficient technology used in the dairy sector. This article will be exploring robotic dairies in relation to how their acceptance was influenced by social and economic factors.

Background

Robotic dairies are an almost fully automated system for milking, feeding, and caring for dairy cows using precision agriculture technology for greater milk yield. Cows can enter the milking station at their own will, where it is electronically recorded via a collar and scanner in the robot that identifies the cow. This allows the system to follow milking patterns, and track each cow's milking frequency, timing and volume. This data can be analysed to improve efficiency and affect decisions. The ability for the cow to be milked at any time they want optimizes their milking frequency, leading to the average milking per cow, per day, to go from 2 times a day in conventional milking systems to 2.17 times a day in robotic dairies.

When the cow enters the milking robot, the robotic suction cups locate the teats where they are cleaned and then milked. The cleaning of the teats significantly reduces the risk of mastitis or teat disease. Whilst in the robot, a blood sample is taken to analyse any nutrient deficiencies to monitor general health of the cow. Based on these readings, the cow is fed a mixed ration full of concentrates personalised for their needs .

Robotic dairies promote the idea of free cow traffic, meaning all cows can eat, drink, rest, socialize, and be milked at all times. Figure 1 shows a typical robotic dairy setup, with milking, feeding, and drinking stations, as well as rest cubicles. The feed channels along the inside of the barn give the cow unlimited access to food meaning more frequent, smaller meals to optimize metabolism for milking and decrease the risk of metabolic diseases. Rest cubicles stationed all throughout the barn keep the cows off their feet, so they are less stressed. The robotic dairy is the best environment for them to produce milk. The free choice of eating, drinking, and milking for the cow makes them more relaxed and less worried about higher ranked cows.

Economic and social influence

The acceptance of robotic dairies has been strongly influenced by economic and social factors, determining if the farmers want to accept the technology or stick to conventional methods of dairy farming. While robotic dairies may be a more efficient and higher yielding way of farming, their adoption depends on cost, return on investment, impact on lifestyle habits, and social appreciation within the farming community.

Economically, the cost to start a robotic dairy can be quite high, but with rising labour costs, return on investment is optimal. The cost to install a singular robot is $200,000 - $250,000, which manages 50 – 70 cows. This can narrow acceptance and installation of the robot to only large-scale farms as they are able to make the investment. The high startup cost and risk with long payback periods can discourage smaller farms. However, at a 5 – 10% increase in milk production and profits, it is estimated that it would take roughly 12 years for a singular robot to pay off its debt in return on investment. The average wage for a labourer on a dairy farm is currently $16 - $19 and rising, meaning the robotic dairy would eliminate the need for a labourer and their training plus the risk of human error. The economical upsides of robotic dairies are slowly starting to appeal to farmers with 1.5% of dairy farms in Australia implementing robotic dairies and that number is rising. The software and analytical side of the robots also create jobs within robotic dairy producers such as LELY and dairy farms themselves, contributing to the economy by providing job opportunities to compensate for labourers that are no longer needed. This shows how economic factors can influence the acceptance of technologies in agriculture.

Socially, the idea of a flexible lifestyle and not having to wake up at 4:30 every morning to milk the cows appeals to many farmers. The main reason robotic dairies are accepted is because that the extra time can then be used on other areas of the farm, leading to a more efficient system and a less rigid lifestyle for dairy farmers. The technology associated with robotic dairies can deter older farmers, as it may be harder to manage. But for the younger generation coming through, it is much easier to manage, and the concept of dairy farming becomes more appealing because of automation and hands-free work. The younger generation also has less of a social attachment to the traditional milking style and the of technology replacing humans.

Conclusion

The acceptance of robotic dairies is heavily influenced by economic and social considerations. The adoption is not influenced by effectiveness alone, but also economic viability and social beliefs. The long-term return on investment, increased milk yields based off the cow's optimal milking frequency, and the ability to have a flexible lifestyle all contribute to the acceptance of robotic dairies. The implementation of robotic dairies is expected to grow in the future as the younger generation of farmers comes through and smaller farms realise the benefits. This will lead to more efficient dairy farming nation-wide and a greater social acceptance of robotic dairies.

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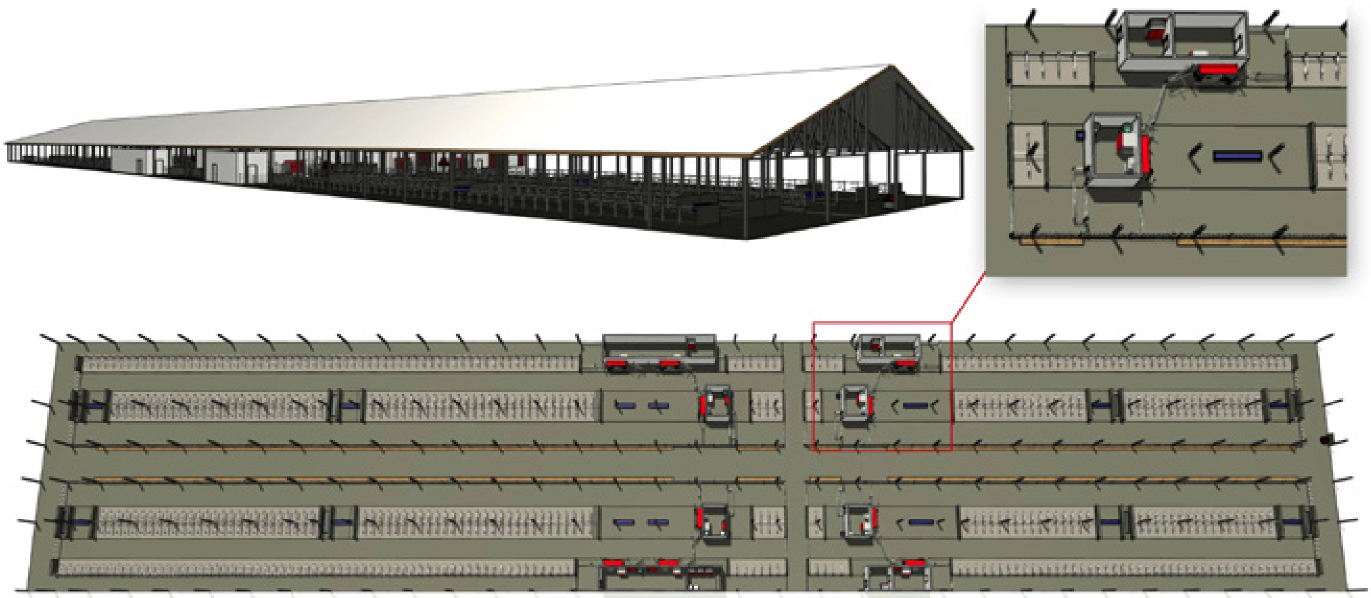

Figure 1: LELY robotic dairy setup example

The application and limitation of carbon dots in nanobiotechnology of agriculture

Words by Peter Papageorgiou (Year 11)

Agriculture

Carbon dots are complex synthetic compounds containing nanoparticles. They possess characteristics of being low toxicity, photoluminescence, and highly solubility, typically ranging up to 10nm. From 2004 to the present day, carbon dots have been methodically developed and as the applications of the technology has expanded to include gene-editing, gene synthesis, cancer therapy, bioimaging, and health monitoring. The applications of carbon dots in agricultural nanobiotechnology and the associated limitations will be the focus of this investigation.

Primarily made of carbon, CQD (carbon quantum dots) have multiple layers of composition that make up its core, surface and even optional additives that chemically alter it for specific tailoring. The core is mostly comprised of sp^2 hybridisation, composed of 1 s orbital with 2 p orbitals to create a structure of a trigonal planar as shown in Figure 1.

This is essentially thin graphite sheets that are smooth to enable electron movement due to their unique properties, permitting freely flowing delocalised electrons. This allows for photoluminescent and light absorption. On the surface, the CQD components consist of sp^3, which serve as the scaffold of the particle that gives it structure and, most importantly, act as the glue of the functional groups. These functional groups include hydroxyl, carboxyl, amino and carbonyl, which provide water-soluble, binding, and photoluminescence properties.

The structure of a carbon dot, with these functional groups, can be seen in Figure 2. CQD's are an extremely viable nanoparticle that can withstand harsh environments; they are highly reactive, yet stable due to their hybridised core and passivation of their surface, which allows for reactivity change. With a great surface area relative to their volume, CQD's are very efficient and effective.

With rapid innovation and development in integrating nanomaterials such as carbon dots into agronomics, the technology can be applied to increase yield efficiency, improve quality and enhance resistance in sustainable agriculture. Essentially, CQDs can be utilised as nano-fertilisers to be sprayed on crops to increase the rate of photosynthesis. This is due to the emission of fluorescent lights in CQD's activating chlorophyll cells, the nutrient uptake for the plant and the faster transformation of electrons in the photosystems. Ultimately, an increase in photosynthesis directly improves the yield efficiency and growth of a plant. Data collected from sources such as ScienceDirect and RCOC find that CQDs in

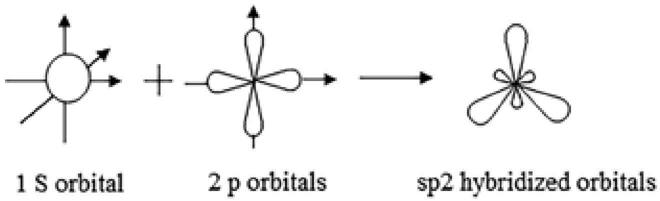

Figure 1: sp^2 hybridized orbitals

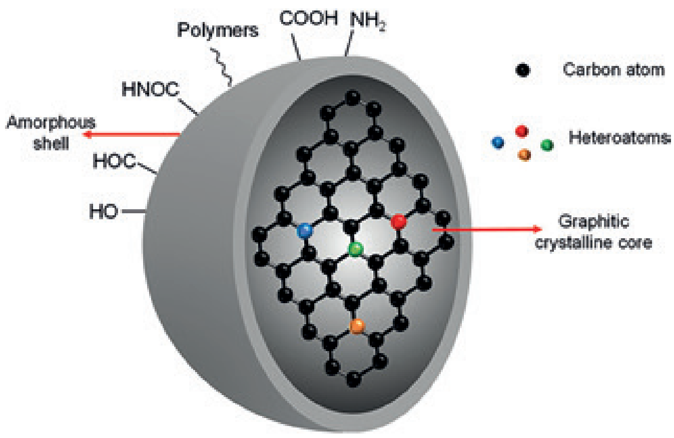

Figure 2: structure of carbon quantum dots

nano-fertilisers effectively increases the soybean yield by 21.5% and 18% in wheat, and on average across most plants, there is a 80% to 150% growth in biomass, which therefore increases yield. Moreover, studies show that CQDs improve the quality of crops due to the absorption of ultraviolet wavelengths, enhancing chloroplast productivity, vitamin activity and metabolism stimulation. Using a foliar spray, the volume of chlorophyll can be enhanced from 9.8% to 50.5%, and catalase can be increased by 162.79%. Thus, effectively strengthening the plant in quality and amplifying optimality. Furthermore, CQDs can create greater resistance in crops to diseases and stress. By promoting the reaction of defensive proteins and antioxidant enzymes, CQDs trigger stress signals that oppose and resist root-rot in plants from 95% to 30%. Due to regulating temperature in plant leaf systems and stabilising crops by 45%, it allows farms to withstand extreme conditions and stabilise food production. As a result, a stable agricultural industry can be made with enforced food security through the

CQD establishment, and despite the high expenses of carbon dots in fertilisers reaching $30 a kilogram, it is used in small amounts and yearly has a net profit that far outweighs the drawbacks and initial cost.

Although carbon dots provide beneficial aid to agriculture, there are some limitations, such as experimental testing, regulations, possible ecological risks, and financial cost. As CQDs in agriculture are a newly emerging product, there is very minimal testing being done in real-world scenarios, and it is more often conducted in stabilised laboratories or greenhouses. Considering this, the legislative framework of CQD in nano-fertilisers is heavily regulated and, therefore, not commercially viable in its agronomic application unless extensive independent testing is conducted. Furthermore, when CQD are tested in labs, there have been reports on soil microbes that have had a certain increase in microorganisms, such as 344.4% in Pseudomonas and 126.2% in Nitrospira, leading to inquiries into whether the same increase promotes the growth of harmful microbials. Additionally, the testing for long-term exposure to humans and the environment is undisclosed. Moreover, the cost of these CQD nano-fertilisers at a grand scale of conventional farming is unknown, and when produced, they are only synthesised in small amounts, which is inefficient. Ultimately, the emergence of CQD in fertilisers carries complications that risk financial detriments for investors as well as shaded public acceptance, resulting in an overall lack of use.

Carbon dots are complex synthetic compounds containing nanoparticles. Primarily made of carbon, CQD (carbon quantum dots) have multiple layers of composition that make up its core, surface and even optional additives that chemically alter it for specific tailoring. With rapid innovation and development in integrating nanomaterials such as carbon dots into agronomics, an example of a societal impact is increased yield efficiency, improving quality and enhancing resistance in sustainable agriculture. Although carbon dots provide beneficial aid to agriculture, there are some limitations, such as experimental testing, regulations, possible ecological risks and financial cost. From here, CQDs require further research and development to minimise risks, with current testing being conducted for large-scale practice. CQD is currently available in some drugs and medicines, health-related therapies, bioimaging and even forensic sciences.

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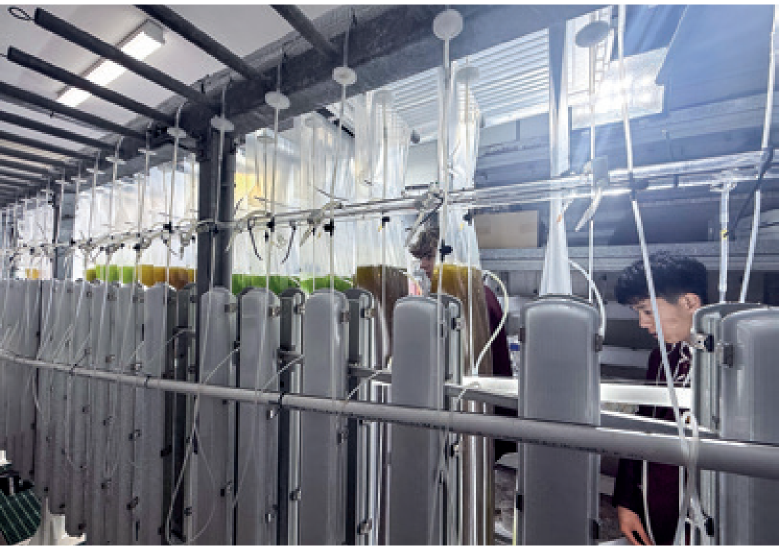


Above: Plant spy agents of the world by Wiliam Beare (Year 3), Dean Dong (Year 3), and Jacky Shen (Year 3)

Seed dormancy and germination: environmental control of plant development

Words by Ansh Tiwari (Year 10)

Biology

Seed dormancy is a biological mechanism that prevents seeds from germinating until environmental conditions are suitable for plant survival. It is a key adaptation that allows plants to persist through periods of drought, cold, fire, and other environmental stresses. Germination occurs only when external conditions such as water availability, temperature, oxygen, and light signal that growth is likely to succeed. This article examines the biological basis of seed dormancy, the environmental cues that regulate germination, and the ecological and agricultural importance of these processes. It also discusses how climate change is disrupting natural germination timing and affecting plant survival patterns across ecosystems.

Seeds represent one of the most important evolutionary innovations in plant life. Inside each seed is a dormant embryo capable of developing into a fully functioning plant. However, seeds do not always germinate immediately after dispersal. Instead, many enter a state known as dormancy, during which metabolic activity is greatly reduced and growth is suspended.

Dormancy is essential because it ensures that seeds do not germinate during unfavourable environmental conditions. If seeds were to germinate immediately after being released, many seedlings would die due to lack of water, extreme temperatures, or seasonal changes. By delaying germination, plants increase the likelihood that at least some offspring will survive to maturity.

The study of seed dormancy and germination is important in ecology, agriculture, and environmental science because it influences plant distribution, crop production, and ecosystem recovery after disturbance.

Seed dormancy: definition and types

Seed dormancy is defined as the failure of a viable seed to germinate even when conditions appear suitable. This state is not caused by seed death but by internal or external mechanisms that prevent germination until specific requirements are met. There are three main categories of dormancy.

Physical dormancy occurs when the seed coat is impermeable to water or gases. Many legumes, such as peas and acacias, have hard outer coats that must be broken down by environmental processes like fire, abrasion, or passage through an animal's digestive system before germination can occur

Physiological dormancy is controlled by internal chemical processes within the seed. Plant hormones play a major role in this process. Abscisic acid (ABA) maintains dormancy by inhibiting growth, while gibberellins (GA) promote germination by stimulating enzyme activity and embryo growth. Environmental cues such as cold temperatures or prolonged moisture can shift this hormonal balance and trigger germination.

Morphological dormancy occurs when the embryo is not fully developed at the time of seed dispersal. These seeds require a period of growth before germination is possible, even under ideal conditions.

Germination process

Germination (Figure 1) begins when a dormant seed absorbs water through a process called imbibition. This causes the seed to swell and activates metabolic processes that had previously been inactive. Enzymes are produced, breaking down stored nutrients such as starches, proteins, and fats into usable energy. The first visible stage of germination is the emergence of the radicle, which becomes the primary root of the plant. This root anchors the seed into the soil and begins absorbing water and nutrients. Following this, the plumule develops into the shoot system, which grows upward toward the surface. Once leaves emerge, the plant can begin photosynthesis and transition from stored energy dependence to self-sustained growth.

Environmental factors controlling germination

Seed germination is highly dependent on environmental conditions. Water is the most critical factor as it activates metabolic processes and allows enzyme function. Without sufficient moisture, germination cannot occur. Temperature also plays a major role. Each plant species has an optimal temperature range for germination. If temperatures are too low, enzymatic activity slows; if too high, proteins may become damaged. Oxygen is required for respiration, which provides energy for growth. Poorly aerated soils can therefore inhibit germination. Light is another important factor for some species. Certain seeds require light exposure to germinate, while others germinate only in darkness. This allows seeds to determine whether they are near the soil surface or buried too deeply to survive.

Ecological role of dormancy

Seed dormancy is an important ecological strategy that increases plant survival in unpredictable environments. It ensures that not all seeds germinate at once, which reduces the risk of total population loss if conditions suddenly become unfavourable. Dormancy also allows seeds to form soil seed banks, which are reserves of viable seeds stored in the soil over long periods of time. These seed banks enable ecosystems to recover after disturbances such as fire, drought,

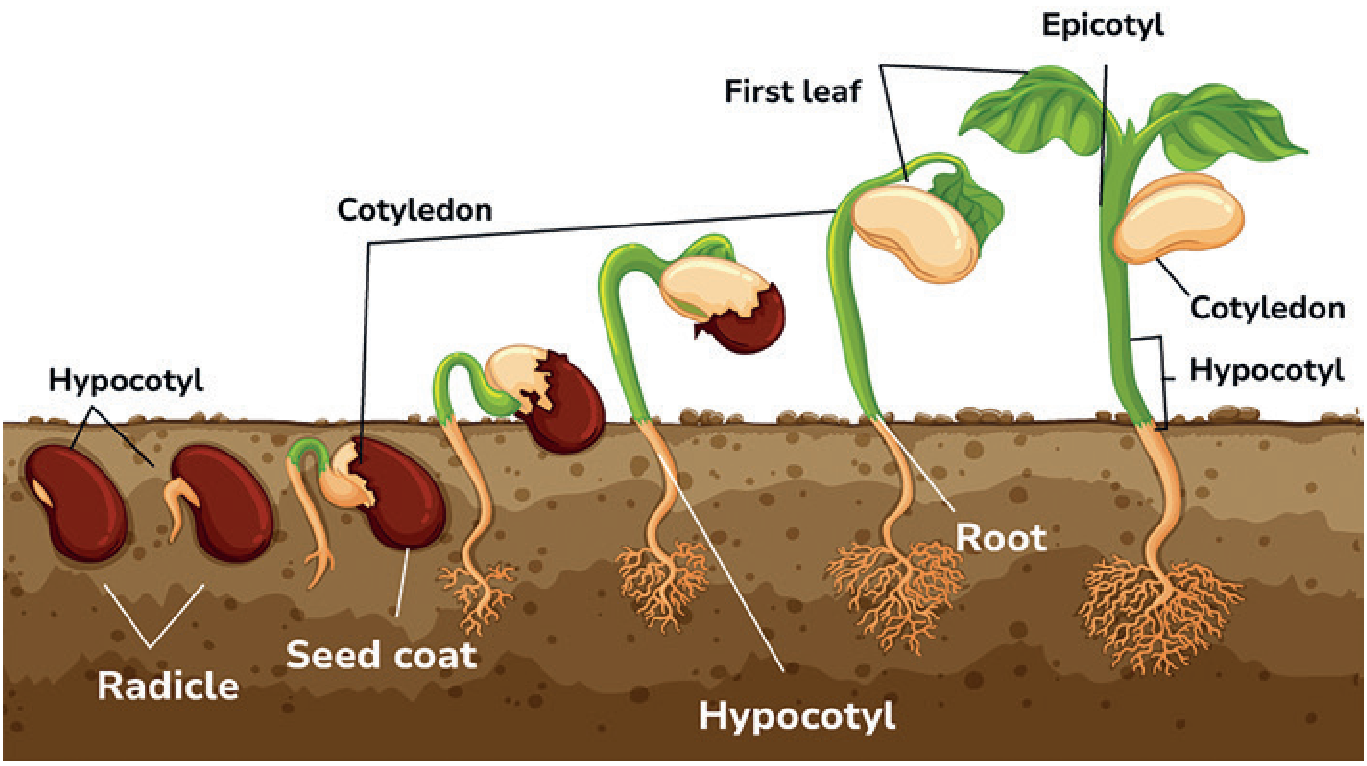

Figure 1: Diagram of seed germination

or flooding. In fire-prone environments, dormancy ensures that seeds remain inactive until conditions created by fire, such as increased nutrients and reduced competition, allow successful germination. This strategy is often described as a form of "biological risk management," where plants spread out germination over time to increase the chances that at least some offspring survive.

Climate change and germination disruption

Climate change is significantly altering the environmental signals that regulate seed dormancy and germination. Rising global temperatures are reducing the effectiveness of cold stratification, which many temperate species rely on to break dormancy. As a result, some seeds fail to germinate at the correct time or do so irregularly. Changes in rainfall patterns are also affecting germination success. In many regions, rainfall is becoming less predictable, causing seeds to germinate during brief wet periods followed by drought conditions. This leads to high seedling mortality. In fire-adapted ecosystems, increased fire frequency and intensity can damage seed banks, reducing the number of viable seeds available for future regeneration. While fire can stimulate germination in some species, excessive heat can destroy seeds entirely.

Agricultural importance

Seed dormancy is also important in agriculture. Farmers and plant breeders must carefully manage dormancy to ensure reliable crop production. If dormancy is too strong, seeds may fail to germinate when planted. If it is too weak, seeds may sprout prematurely, reducing crop yield and quality. Modern agriculture uses techniques such as selective breeding, chemical treatments, and controlled storage conditions to regulate dormancy. Understanding these processes is essential for improving food security, especially in the context of climate change.

Conclusion

Seed dormancy is a crucial biological adaptation that allows plants to survive in unpredictable environments by controlling the timing of germination. It is regulated by internal hormones and external environmental signals such as temperature, moisture, and light. While dormancy has enabled plants to persist for millions of years, climate change is now disrupting these natural systems, leading to reduced germination success and increased ecological instability. Understanding seed dormancy is therefore essential for conservation, agriculture, and ecosystem management in a rapidly changing world.

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A unique perspective on evolution, the gene centred view of natural selection

Words by Charles Li (Year 12)

Biology

Introduction

"Survival of the fittest" is a common phrase in modern culture, often utilised to describe someone being bested due to a lack of abilities. The phrase originates from the theory of natural selection, describing the process of some animals within the same species possessing superior traits that allow them to evade predators and locate food better than others, assisting their survival. Nowadays, this phrase is uttered to describe anything from a company besting another in terms of sales to being dramatic phrases in reality TV shows like Survivor with little consideration of the origins and implications of the phrase. If you were asked to name what survives to be the "fittest", the obvious answer is individual organisms such as plants or animals, but how about a gene? Why is that even a possibility and how would that even work?

The principle of evolution

The theory of evolution was first formulated by Charles Darwin in 1836 but was not formalised until the publication of his famous volume, On the Origin of Species by Means of Natural Selection in 1859. The theory proposed the 5 structural principles of natural selection: variation, inheritance, selection, time and adaptation. Darwin's initially proposed theory was incomplete regarding the processes and origins which led to each of the principles; however the core principles have remained prominent in modern day research. Modern applications of his principles can be summarised as genetic mutations allowing for small variations between parents and their offsprings, leading to surviving organisms possessing a slightly altered genome shown in Figure 1. This usually genetically superior genome is then able to be passed onto the organism's offsprings, allowing for inheritance and further variation. This process is simplified in explanation and usually organisms have little to no noticeable mutations from their parents, leading to many generations of cumulative variation to result in the process known as adaptation. The core process of species specialisation through organisms as proposed by Darwin has been the predominant theory regarding evolution for decades. However, despite the core principles being outlined by Darwin in 1836, many central processes such as what the earliest emergence of "life" actually was or how the first molecule of information came to be remained unknown. This has led to many scientists developing hypotheses regarding what the primary unit of life was, one such theory was proposed by George Williams.

The gene driven world

The gene centred view of evolution theory (commonly known as the selfish gene theory), was first developed by George Williams in 1966 and popularised through Richard Dawkins' book The Selfish Gene in 1976. The theory primarily operates on the concept of natural selection and evolution occurring on different level of genes, instead of the individual organisms. A key notion of this theory however is not to suggest consciousness of the genes, nor their intentional behaviours, only that they operate in this "selfish" manner due to how natural selection leads to the extinction of non-optimal genes. These human-like terms as chosen by Dawkins was to primarily simplify the otherwise convoluted explanation of these behaviours and to humanise these genes to allow easier understanding. This theory was established based on the RNA world hypothesis, the theory that the first signs of what is considered "life" on earth began with RNA molecules. The core implications regarding the RNA world hypothesis are mostly irrelevant to the selfish gene theory, however the theorised process by which life originated from in the RNA world hypothesis is pivotal to establishing the central idea of how a gene driven world is even possible.

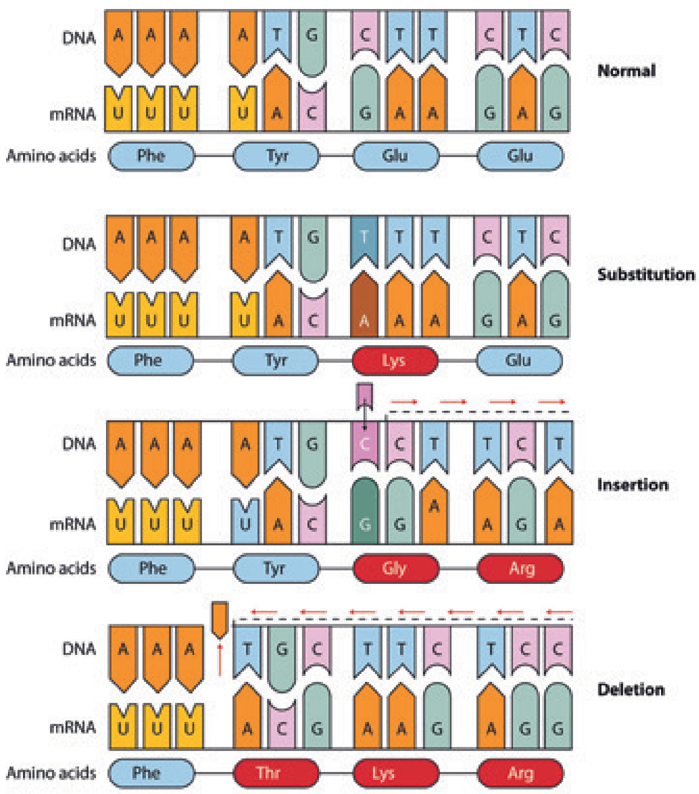

Figure 1: Types of mutation

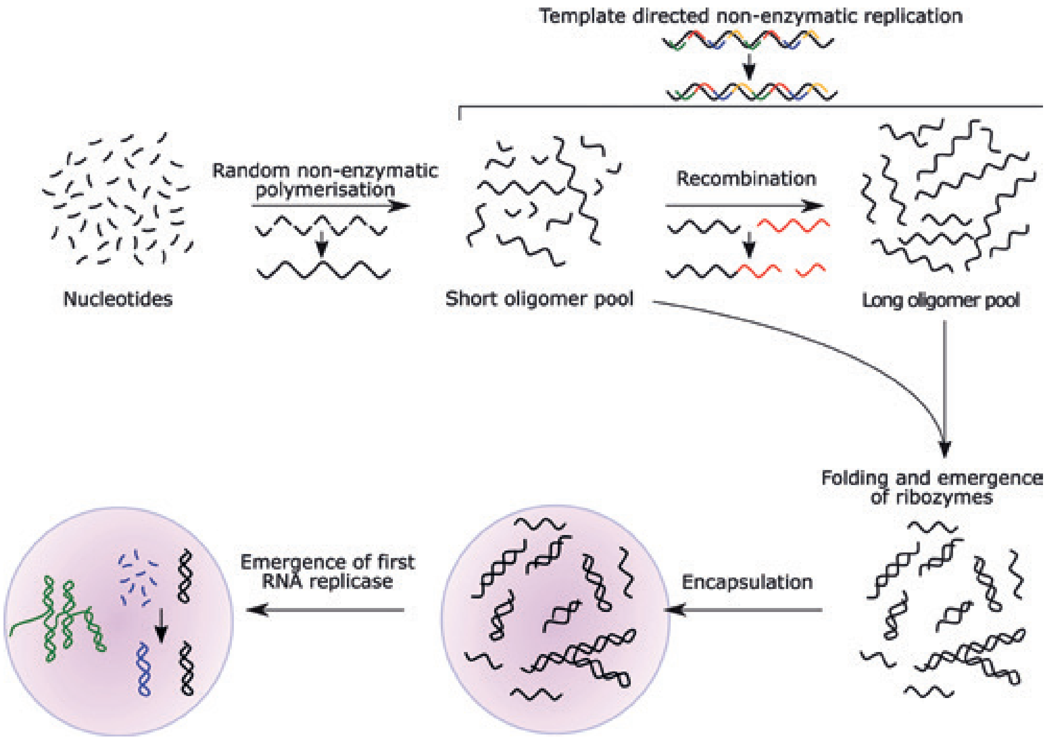

Figure 2: infographic outlining the key steps of how the first RNA molecules could have been formed

The beginning of life

As per the RNA world hypothesis, during prehistoric earth, the environment consisted of a violent cocktail of various molecules and particles. These molecules and particles varied significantly in composition and energy, allowing for a multitude of different reactions to occur, combining different molecules to form random products. Many of these products were unstable or simply could not interact with the world around it, leading to eventual decomposition. Throughout the millions of years of random combinations and decompositions of molecules, eventually, one particularly high energy photon interacts with some molecules to form a larger molecule that was not only stable but also undergo replication. Although most of the details of this initial molecule are still heavily uncertain, the theory proposes that this molecule was the ancestor to all life on earth, the first RNA molecule to be created (Figure 2). This RNA molecule then replicates itself through attracting and binding with other RNA nucleotides and lengthening its sequence, eventually creating the first gene. This gene is thus proposed to be the foundation of life under this theory, as it is the first object which can not only create identical copies of itself, but also exhibit traits that can affect its interaction with the environment. These two core principles regarding what can and cannot be titled with the founder of life is what led to the gene being the only remaining choice. Smaller molecules, such as single nucleotides are capable of replication, however it does not exhibit traits which can affect the way it interacts. On the contrary, a larger molecule, such as a chromosome can not only replicate and exhibit varying traits, however its ability to maintain its structure as a single cohesive unit eliminates its possibility, as then it cannot be selected for. A gene is situated perfectly in the middle of these, being a long enough stretch of DNA or RNA to exhibit a trait, while still stable and short enough to be able to be identically copied over generations. This led to the gene being hypothesized as the unit of natural selection, led to an entirely new perspective on viewing evolutionary traits and behaviours.

Being selfish is key

Under this theory of evolution, Dawkins suggests that each gene is created with the sole purpose of propagation, to develop new copies of itself and ensure its own survival. Dawkins draws this not to suggest sentience to genes but instead to highlight how the process of natural selection has caused surviving genes to behave in a specific manner, as genes which did not possess advantageous traits to further its own duplication would simply not outlast other genes with better traits in an environment with limited resources. Dawkins argued that almost every behaviour seen in organisms today, from bees co-operating with its hive to two lions fighting over territory, can be linked to a strategy that helps their genes survive and replicate. In Dawkins' words from The Selfish Gene, "we are survival machines – robot vehicles blindly programmed to preserve the selfish molecules known as genes." This idea of every gene being optimised for its own survival and replication and organisms simply being carriers of these genes is the crux of the selfish gene theory and serves as a logical explanation for otherwise seemingly detrimental behaviours often seen in organisms.

The importance of family

The most prominent example of which is exhibited through actions taken for the detriment of the individual organism to benefit the overall group its apart of. Although to our minds, helping someone close to you seems logical and expected, however when viewed from a purely survival basis, these behaviours are often altruistic, and natural selection suggests that these traits should be extinct. The behaviour of California ground squirrels can be analysed to explain this point, with female squirrels often letting out a call to serve as an alarm to warn nearby squirrels about predators. However, this call can also be heard by the predator, leading to the squirrel releasing the call to be targeted instead, leading to a higher rate of fatality for the individual. Thus, this gene would be detrimental to the squirrel which carries it, which intuitively

Figure 3: California ground squirrel on rock

Figure 4: The chicken-jockey scene from The Minecraft Movie

should make it unsuitable for natural selection. However, when considering the grouping tendencies of California ground squirrels (Figure 3) and examining the maths behind gene inheritance, the behaviour can be seen as sacrificing one individual for the survival of the gene, something ingrained into our subconscious through evolution that we simply view it as being normal. Through simplifying real-world behaviours and the distribution of DNA through sexual reproduction, a thought experiment can be undertaken to demonstrate this principle. The first individual can be thought of to contain 100% of the relevant DNA, leading to any first-degree relatives such as parents, children and siblings to contain 50% of the DNA, and thus second-degree relatives to contain 25%. If the first individual were to die due to the altruistic behaviour, if at least two first degree relatives were to survive, the overall survival of the gene contained within the DNA would not be negatively impacted. As the majority of animals have a multitude of offsprings, this allows the sacrifice of one individual in the population to allow the better propagation of the gene. To further this with real data, in a study conducted to assess the frequency of the call gene amongst different gendered California ground squirrels, male squirrels (who tend to live isolated from family members) have a much lower frequency of giving out warning calls than females, suggesting the "selfish" nature of the gene.

The birth of memes

Memes are a very well-known term in modern society, especially to younger individuals who frequent the internet. Memes are commonly defined as interesting or amusing videos, images or simply ideas that spread widely online through social media, with contemporary examples including the "Chicken-Jockey" scene from The Minecraft Movie (Figure 4) or the 100 men versus 1 gorilla debate. Despite the widespread usage, many people do not know that the term first originated in the book The Selfish Gene, where Dawkin introduces a new term, he invented to describe internet phenomena that exhibited behaviour similar to genes, coined as "memes". He likened the behaviour of genes to these "memes" in how they are created through sheer chance and spread with the sole purpose of propagating the trend to keep it relevant. These internet phenomena served as an extremely useful metaphor to illustrate the lifeless nature of this theory, how these images and videos have no conscious or life, and are only being spread through means of other conscious beings serving as vehicles. This metaphor also allows the process of natural selection and mutation to be highlighted, with memes changing through time as people add or remove components to it, until the meme inevitably fades back into obscurity when internet culture no longer values it, being analogous to the extinction of a gene. Dawkins' invention and popularisation of this idea of memes have also led to the development of memetics, the study of memes, contributing to both studies of psychology and anthropology.

Why is this theory not widely accepted?

Fundamentally, the selfish gene theory exclusively focuses on how simply chance and probability has led to the selection of specific traits within organisms, neglecting the consciousness of organisms or complexities of epigenetics and genetic actions. Under this theory, genes are simplified to only an individual fixed factor that affects an organism in a certain way, whereas modern research has revealed that typically, many genes compose of a genotype, which then gets expressed as the phenotype such as represented in Figure 5. Environmental factors affecting each organism due to epigenetics is also unexplained under this model, as it emphasizes DNA as the sole unit of transporting information.

Other specific flaws with the theory include why sexual reproduction would exist, as it only preserves up to 50% of the original genes as opposed to asexual preserving 100%. However, some explanations can be reasoned for this phenomenon, such as the genes that regulate the sexual reproduction of organisms have a unique benefit from reproducing sexually, leading to them passing these sexual replication genes onto further generations at the detriment of other genes. Another explanation could be simply that the advantage to the organism due to sexual reproduction is too great that asexual strands existed at one point but were eliminated through natural selection, leading to a compromise scenario where they are forced to not pass on all their genes to ensure survival.

Conclusion

The selfish gene theory was a grounded and innovative theory which allowed the explanation of behaviours that seems counter-intuitive under other models. The impact of this theory also extends further than evolution theory, as Dawkins references cultural phenomena as a metaphor for his theory, establishing the term "memes" and consequently founding memetics, the studying of cultural evolution.

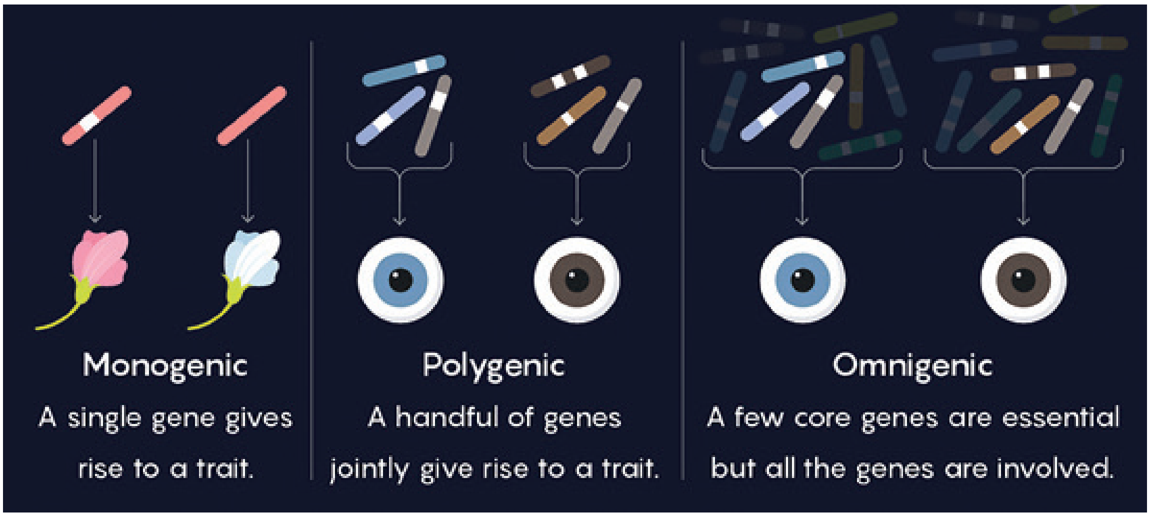

Figure 5: how many genes are at work

However, the overly simplistic basis of this theory leads to many complications when applying this theory to wider circumstances and diminishes its practical application. With further development, this theory could allow the revolutionize our understanding of evolution, survival and genomes, lead to new potential for treatments by formulating better prediction of mutations in diseases or developing more gene targeting treatments. After all, we're all built selfishly, it only makes sense that we take advantage of this ourselves.

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Colossal Biosciences' woolly mouse as a step towards de-extinction

Words by Charles Tang (Year 11)

Biology

Introduction

There are currently 48,600 species on the Earth threatened with extinction. Instead of focusing on recovery efforts such as habitat restoration or captive breeding, Colossal Laboratories & Biosciences, the world's first de-extinction company, has approached the threat of extinction differently. After founding in 2021, cofounders Harvard geneticist, Dr George Church and entrepreneur Ben Lamm have sought to engineer animals "functionally identical to extinct [keystone] species" which will replace an extinct species' niches, rebalancing the ecosystem. After utilising CRISPR Cas-9 to modify the genome of grey wolf embryo, Colossal Biosciences has recreated the dire wolf and is now focused on repeating this with other extinct species, such as the woolly mammoth. However, in doing so, funding is taken away from traditional conservation practices whilst the applications of it are ambiguous. This article will consider how well Colossal Biosciences has currently measured up to its goals for the woolly mammoth project, which include de-extinction of future elephants, developing new tools and the understanding of how genetics impact traits. To restore the woolly mammoth, Colossal Biosciences has listed a 10-step process, seen in Figure 1, aiming to produce mammoth-like Asian elephant embryos by 2028. This process must overcome issues associated with the sequencing of woolly mammoth DNA including sample collection and identifying and inserting the genes to hybridize the cells that then undergo somatic cell nuclear transfer (SCNT), the placement of a nucleus of a somatic cell, inside of an enucleated oocyte.

Permafrost preservation within Siberia and Alaska has allowed many woolly mammoth samples to be recovered, including full tusks, cheek teeth and rib fragments as well as soft tissues allowing for DNA and RNA mapping. DNA can be extracted then amplified through PCR by using a hammer and chisel, or Dremel tool to prepare bone and teeth samples. DNA is generally recoverable due to its stability, sometimes lasting millions of years, but RNA rarely remains after death due to RNAses, enzymes that rapidly break down RNA. This makes it difficult to study insights RNA can provide about how cells function, develop and respond to their environments. Genome mapping tools are software used align raw genetic data to their gene loci based on a standard reference's allowing for comparisons to be made. When comparing the mismatch rate of aligning aRNA sequences to Asian elephant transcriptome, Bowtie2 had a lower mismatch rate compared to other software such as Bowtie and BWA, especially for ultrashort sequences. This was advantageous for minimising misalignments and increasing accuracy when aligning the even more fragile and degraded woolly mammoth samples. However, genome mapping tools depend on a standard

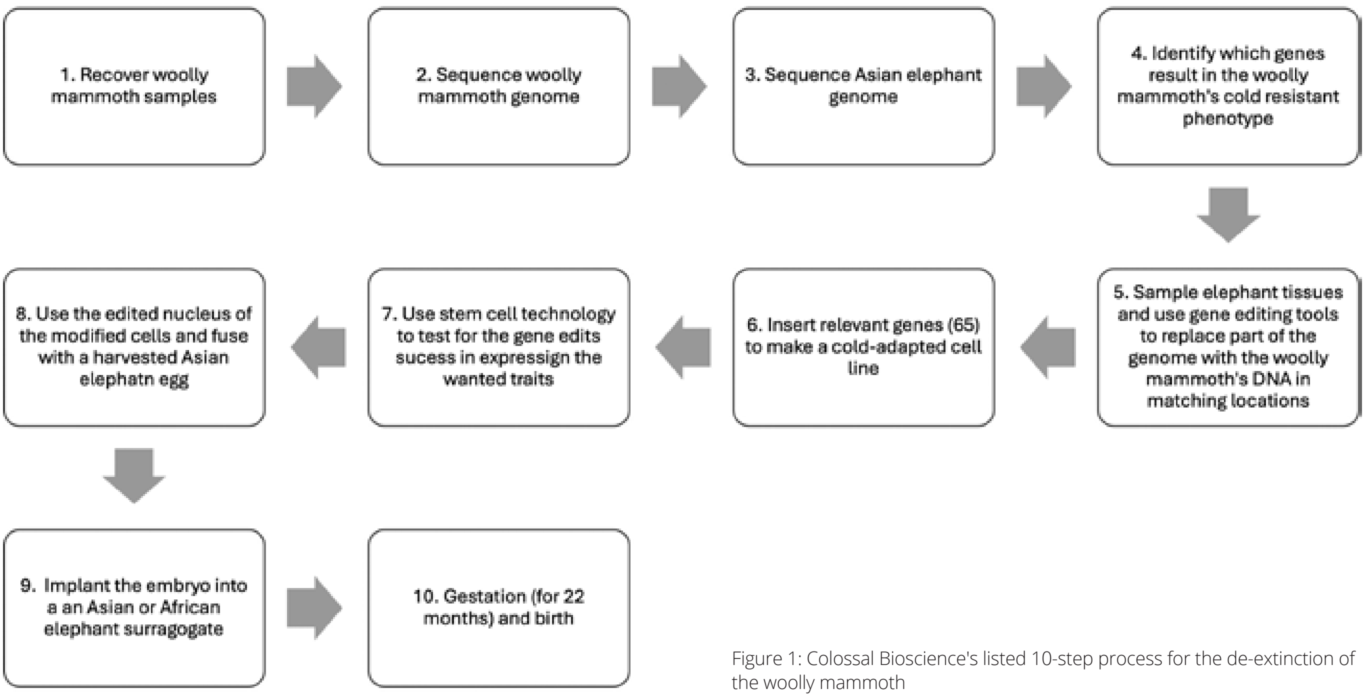

Figure 1: Colossal Bioscience's listed 10-step process for the de-extinction of the woolly mammoth

Figure 2: Woolly mice

reference to filter and assemble the sequence, so references that themselves are incorrectly sequenced can result in accumulating mismatches. This is relevant because there are limited sequences of woolly mammoth aRNA that new sequences can be compared to, increasing potential for false positives.

Bowtie2 allowed researchers to identify "300 protein-coding mRNAs and around 60 different microRNAs in woolly mammoth skeletal muscle". However, similar species such as the Asian elephants have approximately 23 thousand protein coding genes which then can undergo alternative splicing allowing for a single gene to produce multiple distinct mRNA transcripts, demonstrating how many more protein-coding mRNAs there are. To identify more, multi-tissue studies, greater optimisations within RNA isolation and sequencing methods are needed. This would provide greater insights into the expression of a desirable phenotype within a genetically modified organism.

SCNT

As part of step 6, Colossal Biosciences intends to insert CRISPR libraries containing woolly mammoth DNA into the genome of an Asian elephant, making changes to its phenotype. This is due to Asian elephants being the woolly mammoth's closest living ancestor, sharing 99.4% of its DNA. After the 65 relevant genes have been inserted into induced pluripotent stem cells, these stem cells can then develop into multiple tissues which can be checked to see if they display the traits of the woolly mammoth, through stem cell embryogenesis. Thus, SCNT can be used for the recreation of a woolly mammoth embryo.

However, SCNT has varying success, especially in this case where hybridized stem cells are to be used. Within interspecies SCNT (iSCNT), when the nucleus and somatic cell are of different species, developmental failure can arise from disruptions in nucleocytoplasmic interactions, mitonuclear incompatibilities and epigentic programming. Firstly, issues can occur within nucleocytoplasmic transport, the movement of molecules between the nucleus and the cytoplasm. This is because within the iSCNT process, the nuclear envelope breaks down and reforms is constructed of mix of nucleoporins, proteins that control the movement of molecules between the nucleus and cytoplasm, from the donor and recipient. Due to species-species differences, this can lead to incomplete maturation which can then impair transport during mitotic division, preventing cell division for growth. Secondly, following iSCNT, mitonuclear communication occurs between donor nuclear DNA, donor mitochondrial DNA and recipient mitochondrial DNA which can lead to dysfunction due to the heteroplasmy, presence of nuclei from different origins. This is because both the nuclear and mitochondrial DNA code for proteins needed to build oxidative phosphorylation (OXPHOS), as they build the electron transport chain together, various membrane proteins that act as enzymes to couple redox reactions, gradually releasing energy from aerobic respiration. If proteins are incompatible, the electron transport chain will be disrupted, impairing mitochondrial function. Additionally, heteroplasmy can lead to dysfunction due to the alteration of cellular metabolism, where gene expression and oxidative stress is altered.

Thirdly, iSCNT technology aims to reprogram the somatic donor nuclei into a totipotent state, so that the hybrid cell can then mimic the developmental processes of a fertilized embryo by being able to specialise into all cell types. However, some somatic nuclei retain epigenetic marks of an adult cell that need to be erased for proper reprogramming and hence allowing for correct nucleus, mitochondrion and cytoplasm crosstalk. If not achieved before genome activation, failed patterns will be copied and expressed, resulting in foetal abnormalities due to incorrect genes being transcribed.

Woolly mice

Despite these possible failure mechanisms, Colossal Biosciences were nevertheless able to achieve iSCNT. In 2025, as a proof of concept, they created "woolly mice", mice with up to seven genes altered, to have a phenotype consisting of curly, golden-brown, textured coats, as seen in Figure 2. To make these genetic changes, Colossal Biosciences combined "RNP-mediated knockout, multiplex precision genome editing, and precision homology directed repair (HDR)". These advanced genetic engineering techniques were able to edit multiple specific genes simultaneously to achieve high editing efficiencies. This showcases Colossal Biosciences' ability to drive predictable phenotypes validating the viability of recreating the woolly mammoth.

Future steps

While the woolly mouse is a significant milestone, Colossal Bioscience's still has significant progress to make to de-extinct the woolly mammoth, including the increased complexities of going from a model species, mice, to Asian elephants. George Church, a cofounder of Colossal Biosciences claimed that to accomplish their goal, 65 genes in an Asian elephant would need to be altered, which increases chances of mistakenly modifying DNA regions similar to the target sequences. Additionally, the understanding of the relationship between editing polygenetic traits and the resulting phenotypes needs further development, especially due to the differences in biological processes within mice and elephants such as metabolism. Also altering the Fabp2 gene, associated with lipid metabolism and fatty acid formation, led to no observable differences within the woolly mice. Furthermore, mice have a 20-day gestation period, much shorter than the 22 months of an Asian elephant which leads to a lengthier and costlier process for evaluating success.

Limitations

However, even if Colossal Biosciences were able to bring back the woolly mammoth, it is ambiguous if it will have its intended effects. Firstly, the woolly mammoths once inhabited Pleistocene steppe-tundra, a vast, cold and dry treeless biome. The biome was maintained by megafauna through processes such as trampling, uprooting and seed dispersal. Church claims that mammoths scraping away layers of snow allowed cold air to reach soil, maintaining the permafrost but after the mass extinction of megafauna ~12-15 ka ago, the lack of trampling led to its melting, which also released greenhouse gases. Therefore, the revival of the woolly mammoth would reverse this process. However, some are sceptical of this. Professor in evolutionary genetics at the Stockholm-based centre for Paleogenetics, Love Dalèn, believes that woolly mammoth de-extinction will not have "any measurable impact" on the permafrost. Also, today the ecosystem is turning from a dry, vegetated land into a peatland. Having the phenotype of a woolly mammoth within the current ecosystem is unlikely help it to survive and bring back the plants and animals the co-inhabited the ecological niche. Additionally, Colossal Bioscience's research requires the use of Asian elephants, an endangered species, which diverts funding that could be otherwise used for other conservation projects such as the International IFAW Asian Elephant Protection (AEP). Colossal Biosciences have received over $558 million dollars of funding, despite uncertainty of its ability to conserve natural habitats, compared to traditional conservation practices. Furthermore, CRISPR-Cas9 still faces limitations due to the chances of off-targeting, which can induce undesirable and unpredictable mutations. When these malfunctioning genes are spread across the population's gene pool, it reduces the chances of organisms acquiring biological fitness.

Applications

However, the need to prevent CRISPR-Cas9 leading to undesirable outcomes has helped develop and refine existing techniques which can be applied in other areas. The woolly mouse serves as a pivotal organism due to the ability to customise the genome, allowing for more accurate models of diseases and observation of relationships between genotypes and phenotypes, having cross-disciplinary applications including neurological research and metabolism. Within cancer research, the woolly mouse has helped scientists to understand the gene-environment conditions that drive tumorigenesis, the process by which normal cells transform into cancerous ones and proliferate to become a tumour. By introducing mutations similar to those in human tumours, it has enabled researchers to observe antitumour immune responses that more closely mirror those of human cancer physiology. Ethical concerns also stem from this, centring on ensuring humane treatment of the mice and minimising harm during genetic modification. Furthermore, Colossal Bioscience's has also used technology developed during their research to develop four of their own commercial ventures, including 'Breaking' which developed Microbe X-32 which is able to breakdown various plastics.

Conclusion

Colossal Biosciences have made significant progress towards the de-extinction of the woolly mammoth, as marked by the woolly mouse. The woolly mouse overcame challenges associated with woolly mammoth DNA collection and failure mechanisms of iSCNT. But to repeat this with the Asian elephant, there are further associated challenges with iSCNT that Colossal Biosciences such as greater regulations as an endangered species and its lengthier gestation period. Currently, the woolly mouse has applications within other fields such as oncology, where genetically modified mice have better mimicked the human physiological responses to tumours. These applications are also seen within Colossal Bioscience's own commercial ventures such as Breaking. However, it is currently ambiguous whether the woolly mammoth will be able to have the intended effects on an ecological niche that no longer exists and raises ethical concerns on how the funding for this project instead have been funded traditional conservation efforts.

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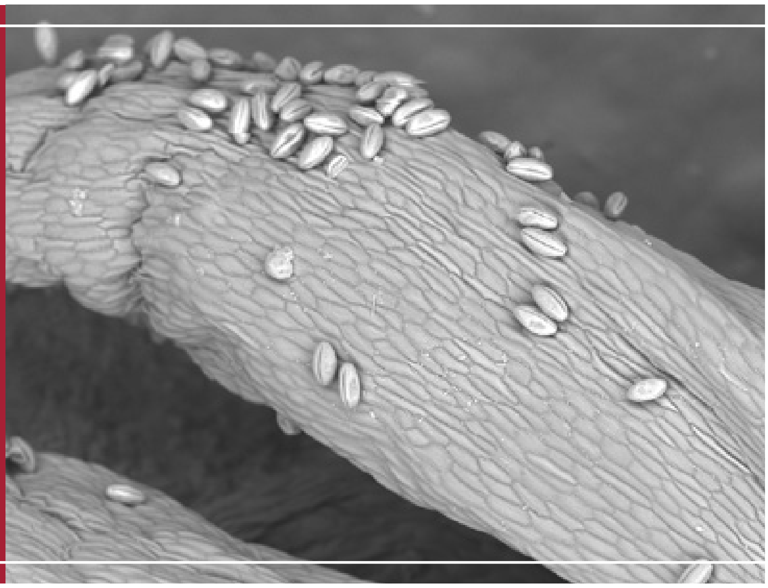
What is this?

Find out what the scanning electron microscope sees on page 73.



Life cycles in nature by Charles Yin (Year 4) and Elon You (Year 4)

Bird Flu

Words by Elon You (Year 4)

Biology

Journal

June 24, 2026

Bird flu was detected in South Australia on the Fleurieu Peninsula. It went on the news while I was driving home from school and I was all like, "Mum! We're going to have severe vomiting and stuff!"

"No, sir! No gastric problems!" My mum later told me to stop overreacting.

June 26, 2026

We were advised by the news to report dead birds to PIRSA Report Suspected Avian Influenza portal.

June 27, 2026

Our family was walking to a symphony orchestra and my brother spotted a possible dead rainbow lorikeet, but we didn't report it.

July 7, 2026

My dad and I were walking to BurgerTec for a snack when I saw a true dead bird on the back of the building. We didn't report it for some reason and I regret not doing that.

July 8, 2026

I suddenly was all over the "Burger Sighting" that I decided to write this.

Also, this morning I ate an egg and totally freaked out.

Figure 1: the brown skua that died at Esperance Wildlife Hospital

Figure 2: A dead Southern Fulmar found at Fowler's Bay

Figure 3: Dead birds were found 2km from Fowlers Bay township after cases in WA

How is Bird Flu transmitted?

1. Egg Consuming

Avian Influenza can be found in a raw egg's yolk, white and skin. They can only come through eating it raw, and they don't come into markets, so this is only a risk for farmers.

2. Animal to Human + Mutation

When an animal transmits the virus to a human, the bird flu virus starts multiplying, allowing them to quickly "unlock" cell walls. This makes the victim contagious.

3. Gastrointestinal Tract

Unboiled (pasteurised) milk from an infected cow or goat can also roll out the red carpet for a virus.

4. Eye / Nose / Mouth (Hand to Face) Contact

Touching an object like an infected egg or bottle of milk and allowing it in your conjunctiva can cause conjunctivitis (pink eye).

Bird flu cannot enter through a human's ears.

What are the symptoms of bird flu for both birds and humans?

Symptoms in birds (and chooks)

In birds, Low Pathogenic viruses and Highly Pathogenic symptoms all depend on the main symptoms:

Sudden death, it just happens.

Neurological changes – Neurotropic diseases are when the virus can break into the bird's protective tissue, causing the inability to control or move the body and making the bird's neck twist, causing it to swim or walk in circles and also causing a loss of coordination. (Sorry for the long sentence.)

Respiratory problems – The virus can make it into the lungs and cause the problems.

Purple tinges – Appear on the comb, wattles and legs. They are purple because of loss of oxygen. Haemoglobin in the blood makes it red. Loss of oxygen can make a decrease of haemoglobin, causing blood to turn purple. Blood turning purple can also be because of blood vessels breaking inside the skin to make the disgusting bluish tinge.

Symptoms in humans

Mild cases

- Conjunctivitis
- Fever
- Muscle pain
- Headaches
- Gassy problems

Fatal cases

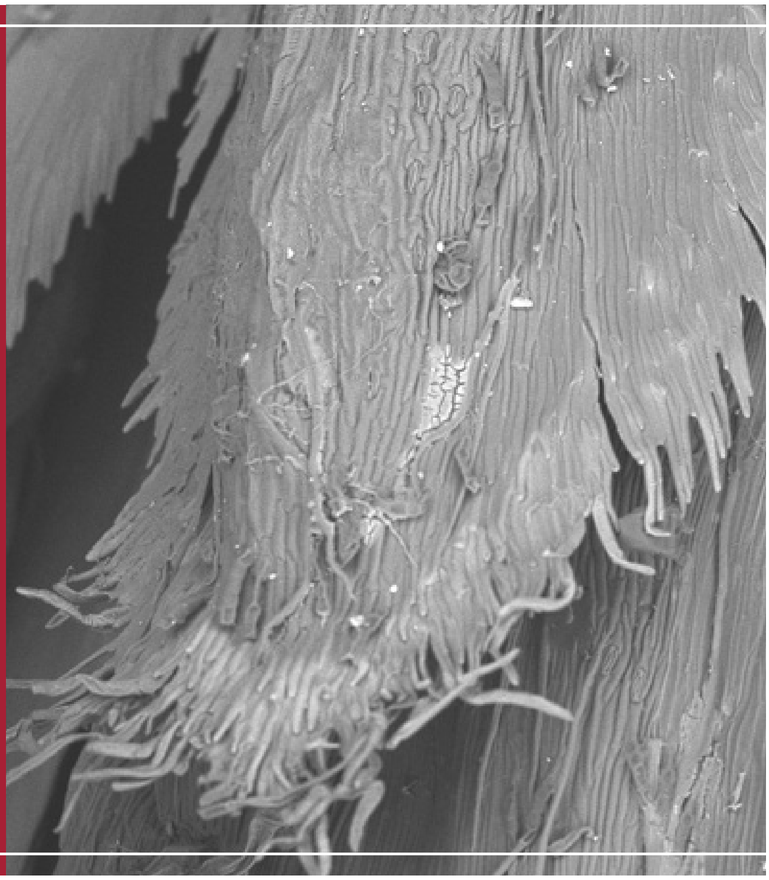
- Breathing (respiratory) problems
- Seizures
- Organs not working
- Pneumonia (inflammation or swelling in lungs)

Conclusion

As a student, I will inform nearby people about bird flu and do all I can (as a 9-year-old) to help mitigate and possibly stop the deadly consequences of bird flu.

What is this?

Find out what the scanning electron microscope sees on page 73.



Prions: the science of misfolded proteins

Words by Finley Turner (Year 12)

Biology

What are prions?

Prions are one of the deadliest and highly researched pathogens on earth – with a mortality rate of 100% – but what are they?

Prions are a non-living pathogen, more specifically, misfolded proteins which cause other proteins to misfold, preventing them from adequately conducting their function. This results in the development of neurological diseases including Creutzfeldt-Jakob disease (CJD), Kuru in humans, Scrapie and Mad Cow's Disease in other animals such as sheep and cattle. Diseases caused by prions are often fatal and despite immense research, no cures currently exist, making prions an especially problematic disease. Prions are also infectious, often spread through inherited genetic mutations, the consumption of contaminated food or medical procedures as they rarely spread via casual contact. Despite the severity of prion–induced symptoms, they often take years to develop. However, once symptoms become noticeable, their intensity exacerbates, often becoming fatal.

The formation and structure of prions

Prions form differently depending on the category which they fall into. Prions are generally classified into three categories: acquired, genetic, and sporadic. Acquired prions are the rarest type, usually caused by direct contact with misfolded proteins. This contact often stems from exposure to contaminated medical equipment or food. Genetic prions are caused by point mutations in the cellular prion protein (PRNP) gene, which normally codes for cellular prion protein (PrP^{C}) – a glycoprotein found predominantly in the nervous system. The most common type of prion is those that are formed sporadically, accounting for approximately 85% of all human prion cases. Sporadic prions form when a PrP^{C} randomly misfolds into an abnormally folded, infectious variant of a PrP^{C} referred to as the 'scrapie isoform of the prion protein' (PrP^{Sc}). The PrP^{Sc} proteins subsequently cause other PrP^{C} proteins to misfold when coming into contact with them, forming more PrP^{Sc}s which continue the process. Although the stimuli which cause such folds to occur are currently unknown, the structural differences between PrP^{C}s and PrP^{Sc}s are more established. The conversion of PrP^{C} proteins into PrP^{Sc}s is the result of a modification in the protein's secondary structure. The secondary structure of a PrP^{C} is primarily composed of α-helices, many of which are converted into dense beta pleated sheets due to misfolding, as seen in Figure 1. The change in the protein's secondary structure significantly

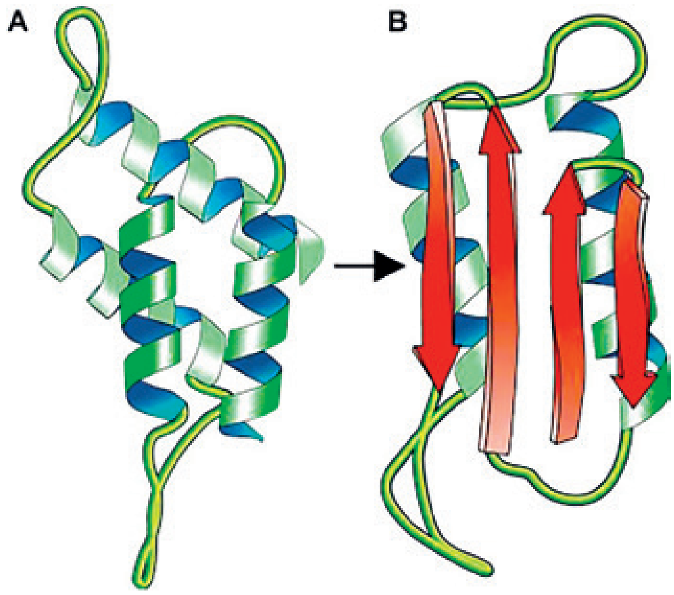


Figure 1: The structure of PrP^{C}s (A) and PrP^{Sc}s (B). The red 'arrows' on B are beta pleated sheets, whereas the green coils are alpha helices.

impacts its tertiary and quaternary structure. Unlike many other proteins, PrP^{Sc} proteins are exceptionally resistant to extreme temperatures, being able to resist temperatures above 100°C and temperatures as low as -80°C. PrP^{Sc}s are also highly resistant to enzymes (such as protease), various chemicals, and sterilisation methods such as autoclaving, boiling, and exposure to alcohol. These resistances are largely due to the high stability within PrP^{Sc}s. Thus, prions tend to be more resistant to various environmental conditions compared to bacteria and viruses, making them extremely difficult to cure.

The effects of prions

As previously mentioned, prions are incredibly resistant to temperature, enzymes (such as protease), chemicals, alcohol, and other sterilisation methods. Prions are also difficult to detect whilst they remain dormant (a state that they can remain in for decades), and they can spread rapidly once symptoms begin to appear. Symptoms of prions-related-diseases include dementia, memory loss, muscle twitching, imbalance, personality changes, insomnia, and more; these symptoms subsequently lead to the death of the contaminated individual. As no cures currently exist, prions are incredibly dangerous – especially compared to other diseases, many of which are easier to detect and cure. Moreover, prions are highly infectious when direct contact is made with contaminated tissues or instruments, although they do not spread easily between individuals. One of the most significant impacts which prions have on the brain is spongiform degeneration, which is the result of prion-related diseases. Spongiform degeneration causes the formation of microscopic holes called 'vacuoles' (not to be confused

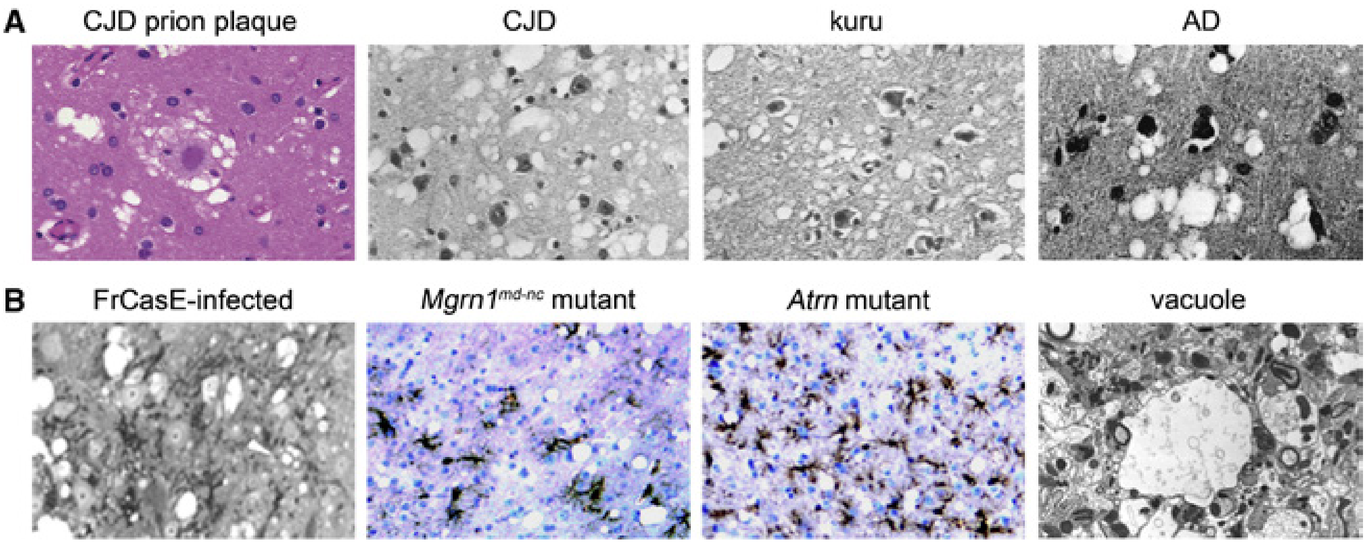


Figure 2: Vacuoles in the brain tissue of different prion diseases associated with humans (A) and animals (B)

with the organelle), which can be either intracellular or extracellular. The size and shape of these vacuoles vary depending on the disease (Figure 2), but the effects are generally analogous; the formation of vacuoles leads to the aforementioned symptoms of prion-related diseases and death.

Developing a cure

Currently, despite having 100% mortality rate and no effective cures, research indicates that cures for prion-related diseases may become a reality in the future. There are multiple areas of research which show great promise of developing cures against prions. One of these fields is the research of yeast. Some species of yeast possess 'anti-prion systems' which inhibit prion infections, preventing prion generation, and cure many prion-related diseases. Yeast prions have a similar structure to many human prions, which means that the anti-prion systems of yeasts may be highly effective in humans. There are many aspects of yeast anti-prion systems, a key example being ribosome-associated chaperones such as Hsp70, Zuo1p, and Ssb1/2. These proteins bind to the end of the ribosome where newly synthesised polypeptide chains exit as seen in Figure 3. They prevent premature or incorrect folding of polypeptide chains through a process called

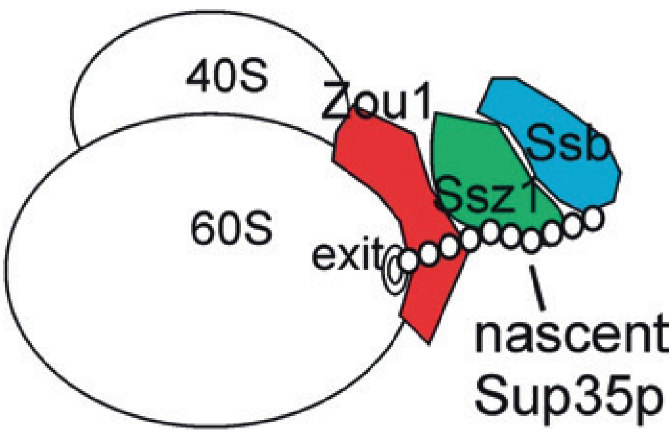


Figure 3: Cotranslation folding guidance being conducted by various types of ribosome-associated-chaperones in yeast

'cotranslation folding guidance', which protects and stabilises the polypeptide chain, as well as slowing the folding process to prevent premature folding. This process ensures that the polypeptide is folded correctly, largely inhibiting the spread of prions in the subsequent protein produced. Although humans also possess ribosome-associated chaperones, they are far less effective when compared to their yeast counterparts. Moreover, the similarity between many human and yeast prion-related diseases means that the higher efficiency of ribosome-associated chaperones in yeast can likely be effectively transferred and applied to human prion diseases. Although the anti-prion systems of yeast seem promising regarding the development of cures for prion-related diseases, the research is still in a relatively early phase. Nonetheless, this could be one of the many avenues which could be utilised to develop a cure for prions.

Conclusion

Although there are immense difficulties associated with developing cures for prions, it is possible that effective cures will begin to develop in the near future. The difficulties of curing prions largely arise from the non-living and stable nature of the pathogens. This makes them exceptionally difficult to destroy as they can withstand extreme environmental conditions. Prions are also difficult to detect and spread rapidly once they become active by inducing the misfolding of healthy proteins. In order to find a cure for prions, scientists have looked toward yeast among other researches. The anti-prion systems of yeast show great promise due to their immense effectiveness and compatibility in humans due to the similarities between human and yeast prions.

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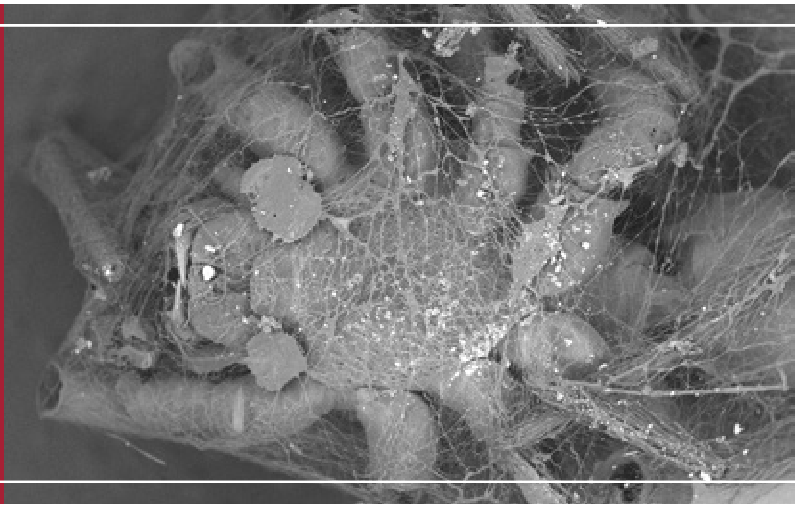
Find out what the scanning electron microscope sees on page 73.



Entomophagy - tomorrow's protein or a fad

Words by Hugo Shaw (Year 12)

Biology

Introduction

Human consumption of insects, known as entomophagy, has existed in some form since prehistoric times as a crucial source of food. Nowadays, with the wider availability of domesticated livestock and large-scale agriculture, animal meat has mostly replaced insect consumption. Despite this, there are growing concerns that current sources of food are obtained unsustainably, such as the high-carbon footprint of beef and other animal proteins (Figure 1). This article will analyse the nutritional implications of consuming insects, their social implications and the environmental impacts of potentially substituting animal farming for insect farming.

Nutritional implications

Insects are renowned for their high protein content, often matching or even surpassing animal meats in terms of protein proportions. Existing research suggests insect protein such as mealworms can support and improve musculoskeletal anabolism, promoting muscle growth and repair. Furthermore, a recent study characterises insects as a viable alternative to animal products, finding that cricket protein was more readily absorbed by the human body compared to beef protein. Additionally, some insects contain bioactive compounds that can have a variety of beneficial effects, including antioxidant properties (potentially decreasing the risk of developing cancer), anti-inflammatory properties (reducing swelling) and regulation of blood glucose metabolism. In contrast, traditionally consumed animal meats (e.g. chicken, beef, pork) have some known risks. For instance, the over-consumption of processed red meats like sausages can increase the risk of heart disease.

Social implications

The myth that insects are unsafe to eat due to bacterial content is actually false; if cooked correctly, bacteria and other harmful pathogens can be killed, ensuring safe consumption. Whilst a societal stigma exists against the consumption of insects (often regarded as 'dirty' and eating them being frequently seen as 'uncivilised') many cultures around the world regularly consume insects for both cultural importance and nutritional value. Various insects, ranging from crickets,

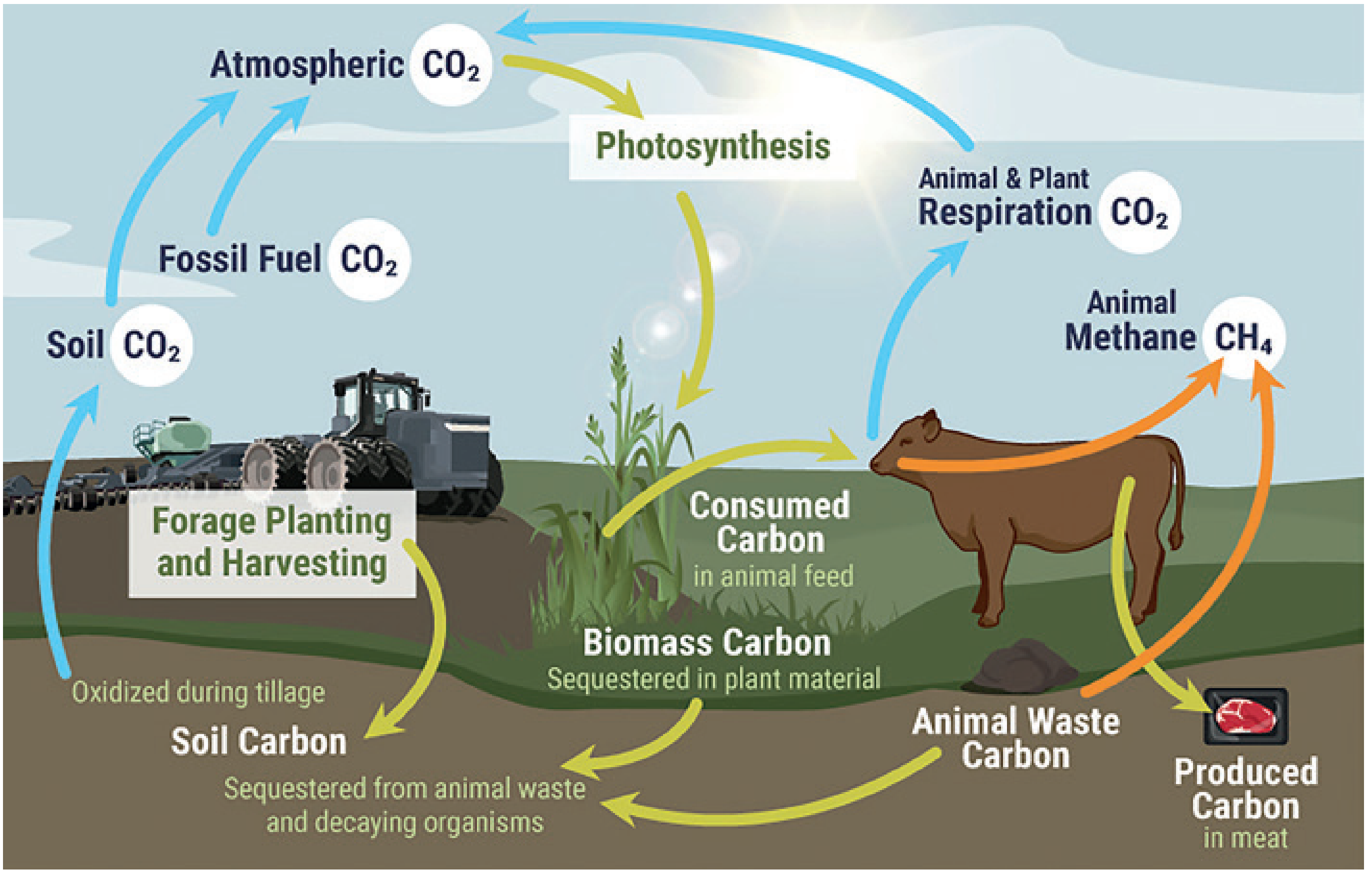


Figure 1: carbon-methane cycles

spiders, mealworms and grasshoppers to ants are cooked and prepared through a variety of methods such as frying, roasting and stir frying. Interestingly, research has found that an increasing number of Westerners (including Australians) are becoming more open-minded to consuming insects, potentially signalling that insects could potentially supersede typical livestock as the main source of protein for humans. For the widespread adoption of entomophagy to occur, large-scale changes to societal attitudes must take place, otherwise a majority of the public would likely be unwilling to accept the possibility of an insect diet.

Environmental implications

In addition to the aforementioned nutritional benefits of consuming insects, there is evidence to suggest that entomophagy may also be more environmentally friendly, compared to traditional animal meats. Insect farming is generally considered as being highly sustainable, with low maintenance costs and a significantly lower carbon footprint (relative to animal meat farming). Insects, such as mealworms, can be fed organic waste (e.g. fruit and vegetable scraps), which leads to 90% less greenhouse gases compared to conventional methods such as composting or landfill. Insects are raised and bred in small, high-density environments such as vertical farming layers. This method uses minimal land by stacking multiple trays of insects, where they can rapidly reproduce. Notably, insect farming methodologies use little water, often requiring only 1.5-11 litres of water for each kilogram of insects

In contrast, beef farming has a significantly larger environmental impact, with high methane emissions (a greenhouse gas that traps heat in the atmosphere), generally long food miles (the distance between where a food product is harvested and where it is consumed) and requires large areas of land. The United Nations found that approximately 14.5% of global greenhouse can be attributed to livestock emissions, predominantly from cattle farming. Thus, it could be reasonably concluded that replacing most (if not all) of animal farming with insect farming could have a noticeable impact on the environment, through lowering greenhouse gas emissions, reducing food miles, conserving land and water and generating a much lower carbon footprint.

Conclusion

Ultimately, the future of entomophagy remains to be seen, although current data suggests that in the near future, entomophagy could be adopted more widely. Given its various nutritional and environmental benefits, one day the consumption of insects could entirely supersede the consumption of animals as humanity's main sources of protein.

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Unravelling Cordyceps

Words by Josh Wang (Year 9)

Biology

The idea of a zombie, the reanimated dead, can be dated back to around 17th to 18th century Haitian folklore where slaves would believe that the punishment for suicide was to become a zombie and roam the lands rather than return to their homeland (I'd love to mention taxonomy). *Cordyceps* is a genus of fungi with over 300 species with majority primarily characterised by their entomopathogenic nature. Cordyceps is most infamous in two different species: *Cordyceps militaris* and *Cordyceps sinensis* are both entomopathogenic and appear as a long orange/brown fungus with spores released from small pores surrounding the cylindrical structure. However, militaris does not require a host to reproduce. Interestingly, the most well-known species of *Cordyceps*, the zombie-ant fungus, is not *Cordyceps* at all but instead *Ophiocordyceps*, a functionally and biologically similar species.

Cordyceps infects insects through spores and takes control of the host body by releasing specific hormones and enzymes that target that insect (Figure 3). This means that *Cordyceps* are incredibly unlikely to infect humans as not only are humans simply too warm of an environment for *Cordyceps* to thrive, but they have been tuned specifically over millions of years through evolution to infect their trademark insect. Once landing on a host body through their airborne stick spores, they produce hyphae which poke through the host's exoskeleton and digest it from the inside before erecting a stalk of the mature fungus, usually on the insect's head, before releasing spores from the elevated position. *Cordyceps miliaris* and sinensis also provide medical benefits as supplements as they can potentially boost energy levels, endurance and respiratory functions.

Cordyceps presents as nature's most elegant yet disturbing creations as through millennia it has honed itself to become a machine for disassembling its host from the inside out and utilising its shell of a body for its own uses. However, towards humans they pose absolutely no threat and may even be beneficial.

Figure 1: *Cordyceps*.

Figure 2 :Zombie ants.

Figure 3: *Cordyceps* infecting an insect.

Deep-sea gigantism

Words by Max Turner (Year 9)

Biology

Have you ever wondered what lies down in the deep ocean? Light cannot reach this environment and the pressure is so high that it can crush a car. The environment seems to be designed to crush, starve, or freeze any creature living there. Yet, somehow life has evolved in an extraordinary way to withstand the harsh environment. This phenomenon is known as deep-sea gigantism and it is one of the most interesting phenomena that has emerged out of the deep-sea.

Deep-sea gigantism is a phenomenon where sea creatures living in deep waters become larger than their shallower water counterparts. This was first discovered in the late 19th Century, when scientists aboard the HMS Challenger discovered giant amphipods and isopods. Their sizes exceeded the shallow water counterparts that scientists had previously observed. The creatures that are affected by deep-sea gigantism can grow 10 to 100 times larger than their closest relatives residing in shallow waters. There is a wide range of sea creatures exhibiting deep-sea gigantism such as Crustaceans (Amphipods, isopods, copepods and some crabs), Mollusks (Squids and some gastropods), Pycnogonids (sea spiders), some fish species, Echinoderms (sea cucumbers and starfish), and Polychaete worms. Some of the most famous examples of animals include the colossal squid and giant squid (Figure 1) and the Japanese spider crab (Figure 2).

To understand why deep-sea gigantism occurs, we must first understand where it occurs, and how it can shape a creature to grow up to 100 times larger. Deep-sea gigantism mostly occurs in the bathyal (1000-4000 meters), abyssal (4000-6000 meters) and hadal (6000+ meters) zones of the ocean. These parts of the ocean feature vastly different environments from the surface that provide many challenges for the creatures living within. Such challenges include extreme pressure, near freezing or even freezing temperatures, food scarcity, and a lack of sunlight.

Deep-sea gigantism does not occur due to a singular factor. It takes multiple factors working synergistically to produce such a phenomenon, although certain factors impact some species more heavily than others. The benefit of large size to creatures living in deep waters can be explained by multiple factors such as Bergmann's rule, the temperature effect, and Kleiber's Law on metabolic efficiency.

Firstly, Bergmann's rule is an ecogeographic principle stating that within a species or closely related species, body size tends to increase at higher latitudes and in colder climates, such as deep oceans. One factor influencing this growth is the increased oxygen availability present in cold water, such as the water in the deep ocean. This is crucial as larger animals naturally need higher oxygen supplies to survive. Furthermore, creatures in the deep oceans have developed their own enzymes suited for the freezing conditions of the deep ocean, which allows them to continue to carry out metabolic reactions. Nonetheless, Bergmann's law cannot fully explain deep-sea gigantism as not all deep-sea creatures experience deep-sea gigantism, and species can exhibit gigantism to differing extent. Some species living in shallow, polar water can also

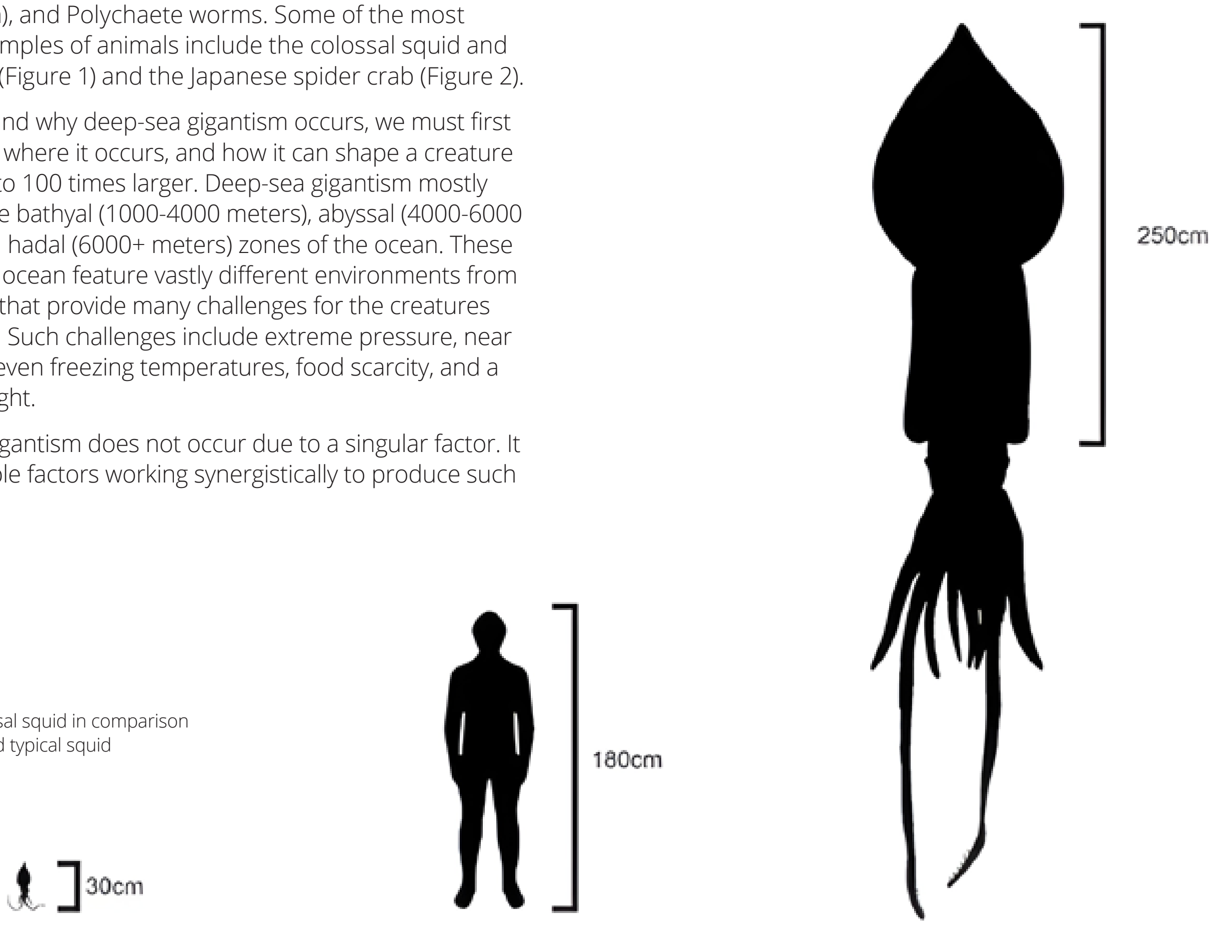

Figure 1: Colossal squid in comparison to a human and typical squid

experience abnormal growth, although this is likely related to the similar phenomenon of polar gigantism. The cold temperatures of the deep ocean also reduce metabolic rate. This causes animals to age slower and live longer lives which allows them to grow to larger sizes.

Figure 2: Japanese spider crab in comparison to a human

Another explanation for deep-sea gigantism can be derived from Kleiber's law, which states that the metabolic rate of an organism scales with its body mass to the 3/4th power rather than linearly. This means that larger creatures have a lower metabolic rate per unit of mass compared to smaller animals. Thus, larger animals use less energy per gram of body mass than smaller animals and can also store more energy due to their large size and lose less heat. This law connects to some of the circumstances of the deep ocean such as the reduced number of predators and food scarcity. The food supply in the deep ocean is limited, meaning that deep-sea predators benefit from increased eye size and body mass as it allows them to search for food more effectively. Furthermore, deep-sea preys have less predators than animals living in shallower waters, allowing them to freely grow to larger sizes. This does not fully explain deep-sea gigantism. Some predators such as giant squid, colossal squid, sperm whales, and sleeper sharks may have forced deep-sea preys to evolve defence mechanisms.

Deep-sea gigantism is a fascinating phenomenon where deep-sea creatures living in the bathyal, abyssal and hadal zones of the ocean experience drastic size increases relative to their shallow water counterparts. There are many reasons for why deep-sea gigantism happens, largely relating to the circumstances of the environment, such as oxygen availability, low temperatures, and a lack of other organisms. The way in which animals have adapted to such extreme conditions shows how deep-sea gigantism is one of the best examples of the impact that the environment has on a species' evolution.

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How can the development of scientific data reduce the negative impact of crown of thorns starfish?

Words by Noah Leathart (Year 11)

Biology

The development of scientific data can significantly reduce the negative impacts of the Crown of Thorns Starfish. This can be done by utilising specific information gained from studying their life cycle trends, such as “Boom and Bust” cycles, their use of chemical cues to avoid predators, find prey, and assess the environmental risks around them. The scientists studying this starfish can drastically reduce the negative impact that the starfish have on reefs and reef ecosystems, particularly the Great Barrier Reef.

The Crown of Thorns Starfish (COTS) are a coral-eating species of starfish native to the Indo-Pacific region which are often found in very high numbers. The starfish can have up to 21 arms covered in hundreds of toxic spikes as seen in Figure 1. Outbreaks of COTS are responsible for extensive loss in coral reefs, especially in the Great Barrier Reef. The starfish eat many of the corals that manage to survive the heatwaves caused by Climate Change and by destroying the coral, the starfish prevent or slow reef adaption. The starfish live in a ‘Boom and Bust’ cycle, meaning they spike in numbers before quickly dropping again. COTS rely on a good sense of smell rather than eyesight to detect chemical cues in the water, these cues include volatile or soluble compounds that the starfish detect using chemosensory receptors located in their sensory organs, allowing them to identify food sources, mates, and predators. These cues allow the starfish to attract and detect chemical compounds which the coral release as food. It also allows them to avoid predators as even faint scents immediately trigger a fleeing response. Finally, intraspecific and stress signals can

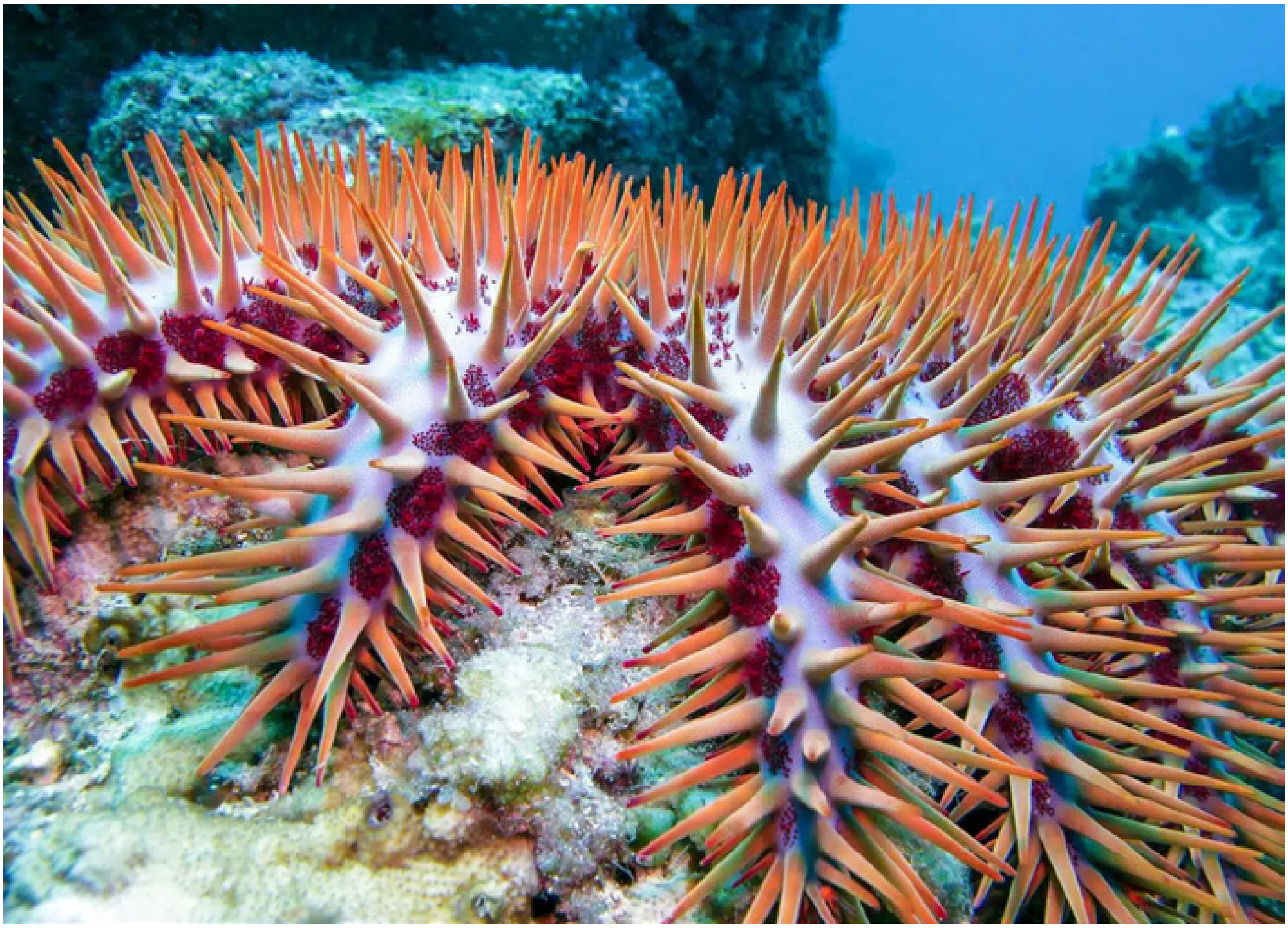


Figure 1: The Crown of Thorns Starfish

indicate the presence of other starfish which allow the COTS to assess environmental risks (specifically if a nearby starfish is injured or dead, it can indicate that a danger is nearby). By isolating and characterising the chemical cues of the starfish, scientists are working towards developing a kind of starfish bait similar to that of cockroach bait.

The scientific discovery of the chemical cues used by the COTS has allowed scientists to create baits to lure the starfish in and cull them more easily. The uses of the scientific data include understanding and identifying outbreaks more effectively and developing tools to control their numbers. Current control programs rely on divers going out and searching for COTS and manually injecting them with bile salts or vinegar. Additionally, surveys are used to identify imminent outbreaks and to monitor existing ones. By reducing the numbers of COTS, the damage to coral reefs is reduced as well. Although they are still being bleached by the rising water temperatures, the release of predatory pressure significantly helps the situation. This also means that the corals that survive heatwaves can then reproduce and create more coral capable of surviving the hotter waters, further increasing their survivability and potentially having a huge positive impact on the current state of the world's temperature and CO_2 levels.

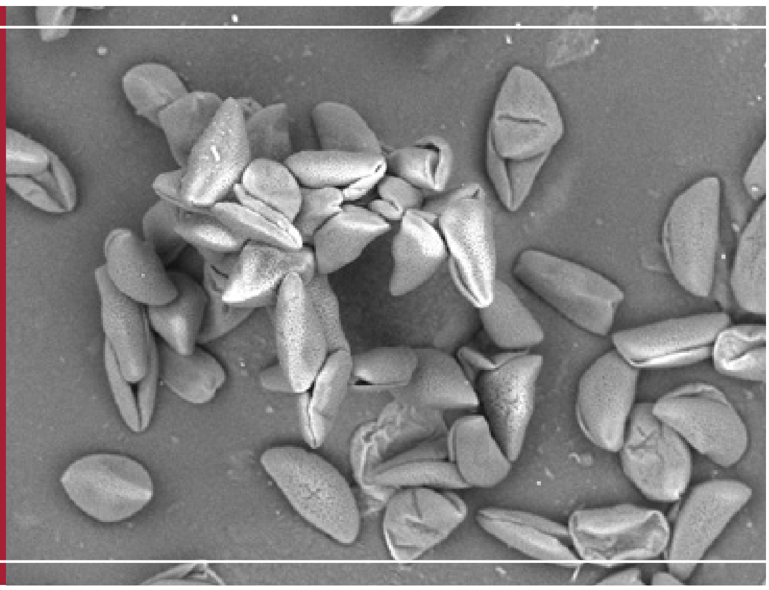
The "Boom and Bust" cycles of the starfish means that the damage they can do to the reef at any time is unknown, but by using data collected through the surveys, the cycles become more predictable and easier to react to, further reducing the potential damage that the COTS could do to the reefs. By utilising all of the data and information gathered, scientists can significantly reduce the negative impact that the starfish has. Firstly, by reducing their numbers, the overall damage being done by COTS to the reef is less. Secondly, increasing the predictability of "Boom and Bust" cycles will help to allow the scientists to react quicker and with higher rates of success. Furthermore, the knowledge gained through this experience can be applied to many other situations of a similar nature, including ones that involve the damaging nature of introduced species to the native flora and fauna. There are many examples of this, such as Red Foxes and Feral Cats, disrupting the balance of a food web by overhunting prey that are not equipped with the necassary adaptations to defend themselves against or escape introduced predators, which damages the stability of the food web.

Despite this, there are potential risks to this method of dealing with the starfish. One potential risk is that excessively culling the population of COTS could be damaging as it removes a food source for predators. For example, removing the starfish would decrease the food source of the Giant Triton Snail. This would meaning that the snail would hunt other sources that are more readily available, killing off that population too, which in turn, would get rid of a predator to potential a producer, maybe a kind of grass, overrunning the reef with the population of grass, completely throwing off the balance of the food web. That said, considering the extensive research conducted by the scientists leading this study, they would be knowledgeable enough to know the appropriate times to cull the starfish population. It is still crucial that scientists are cautious due to the unpredictable nature of the species. If they over-cull the population while it is in a "Boom", when it inevitably "Busts", the population may become endangered or even extinct.

The creation of a baiting technique to lure in the Crown of Thorns Starfish based on their reliance on chemical cues, has been a breakthrough in the struggle against this damaging species, going back to at least 2018. The reduction of numbers and the increase in predictability through surveys and studies has proven a successful endeavor as it is now easier to reduce the damage caused by the COTS by mediating their population.

What is this?

Find out what the scanning electron microscope sees on page 73.



How can plastic-eating enzymes be a biological solution to reducing landfill?

Words by Adrian Shiu (Year 12)

Chemistry

Introduction

Plastic production continues to increase as the population increases over years, from just 2 million tons of plastic in 1950 to over 450 million tons in 2026. The primary reason for the mass production of plastic is due to its versatility and convenient use in various applications, including food packaging, constructions, and home appliances. However, common single-use plastics can introduce serious environmental issues such as threats to marine species and health issues if not properly managed. Plastics are difficult to recycle due to their complex chemical structures and cost; thus, plastics are often placed in landfills. This article will evaluate whether plastic-eating enzymes have the ability to effectively reduce plastic wastes and promote recycling.

Background Information

Scientists from the University of Portsmouth had developed a "super-enzyme" – a combination of two specific enzymes, PETase and MHETase. PETase was originally discovered by Japanese scientists back in 2016, extracted from *Ideonella Sakaiensis*, a type of bacterium. The bacterium originally adapted to secrete PETase to break down plastic in response to their surrounding environment. Polyethylene terephthalates (PET) is a common lightweight thermoplastic polymer that is highly durable, used for plastic bottles and containers. Mono-(2-hydroxyethyl) terephthalic acid (MHET) is an intermediate that is produced from the degradation and breakdown of PET, that will be used further to hydrolyse into raw materials. The two-step hydrolysis process is shown in Figure 1.

PET (polyethylene terephthalates) can be broken down into MHET through PETase-catalysed reaction. PETase attacks the surface of the plastic and converts it into small water-soluble intermediates. MHET is then further broken down into TPA (terephthalic acid) and EG (ethylene glycol), which can be recycled or consume by bacteria.

Ideonella sakaiensis has specific genetic information stored in its DNA to code for specific amino acids, enabling the self-production of enzymes. During transcription in the nucleoid region, with the help of RNA polymerase and free RNA nucleotides, a messenger RNA is produced and travels to a ribosome. Next step in translation, the ribosome reads the mRNA and orders the amino acid specially to form long polypeptide chains before folding into a precise 3D shape to form either PETase or MHETase. These enzymes are naturally produced by *Ideonella sakaiensis*.

Scientists can cut these specific genes and insert them into other host bacteria, generally *E.coli*, which is widely studied. This process is called genetic engineering. Scientists decided not to use *Ideonella sakaiensis*, as they have a slow replicating time (3.6 days), comparing *E.coli* (22-40 minutes). *E.coli* are grown and produces specific enzymes which will be extracted and purified for the two-step hydrolysis reaction above. Both hydrolysis reactions take place in a bioreactor environment, which is a specialised container providing the optimal conditions such as pH and temperature to increase the rate of hydrolysis reactions. In hydrolysis, the enzymes are able to disrupt the ester links between the PET polymer with the addition of water, breaking long complex chains into smaller sections. However, prior to hydrolysis, PET plastic first undergoes mechanical and thermal processes including shredding and heating. As PET has a highly rigid polymer structure, mechanical shredding breaks plastic down into a form of powder, increasing the surface area to volume ratio,

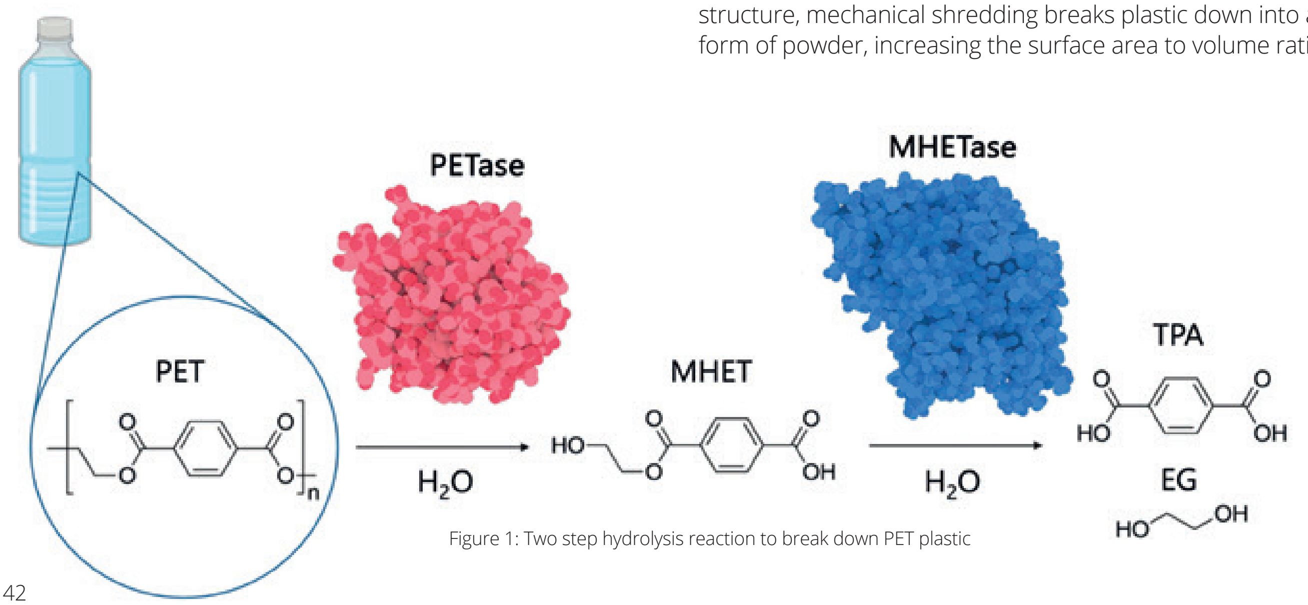


Figure 1: Two step hydrolysis reaction to break down PET plastic

allowing a higher exposure of surface for PETase to attack. Thermal heating causes the particles to vibrate due to a gain in kinetic energy, allowing the intermolecular forces to be overcome, hence allowing PETase to target its active site towards specific substrates.

Why do we need this technology?

The environmental issues surrounding plastic waste and pollution had influenced scientists to utilise enzymes from bacteria to develop an effective method to breakdown PET plastic. Plastic waste not only take up majority of spaces in landfills but also in oceans. Over 40% of ocean surfaces are polluted with plastics, with experts predicting that the number of plastics will outweigh marine organisms by 2050. When referring to landfill, over 84% of single plastics are transported to landfills in Australia. These plastics are non-biodegradable, lasting for long duration (20 to 500 years) with the possibility to release toxic chemicals into the atmosphere and nearby water systems. Plastic-eating enzymes can breakdown plastics to reduce their volume in oceans and landfill which can positively influence the living environment for marine animals, humans and land used to place waste plastic.

A major reason for manufacturers to choose to maintain traditional mechanical recycling method is due to its low cost. Additionally plastic recycling also causes them to worsen in properties. However, plastic-eating enzymes are designed to break polymers into exact monomers used to build PET to ensure plastic of virgin quality. This suggests that PET plastics are able to be reused in infinitely, reducing expenses required to purchase new raw materials, providing possible economic benefits to manufacturers.

The design of plastic-eating enzymes has caught the attention of corporations and governments, as they have provided initial fundings to allow further research and building of equipment. COG-UK, a corporation had funded $25,000 to a university for research into further enzymes possible to degrade plastics. Additionally, the French government had granted a funding of $11.4 million to Carbios, a corporation researching into plastic degradation. Furthermore, governments have globally introduced plastic taxes, where new plastics are priced more expensively, appealing the use of plastic-eating enzymes to industries in order to reduce cost of productions, aiming to deaccelerate the usage of plastic.

Despite utilising “super-enzymes”, it is nearly impossible to match the rate of plastic production. It would be difficult to collect existing plastic from oceans and landfill globally, which means the enzymes cannot perform their functions. In order for enzymes to work, plastics are collected and processed in the bioreactor. This requires transporting plastic to industries which would increase carbon dioxide emission, increasing greenhouse gas concentration. Thus plastic-eating enzymes is not only beneficial to plastic reduction but also a trade-off to carbon neutrality.

Conclusion

Plastic-eating enzymes are influenced by the increasing amount of plastic pollution, and these issues must be addressed to ensure a sustainable future. Super-enzymes demonstrate potential in reducing plastic waste by promoting enzymatic recycling to industries due to its ability to break PET into monomers with perfect quality. However, these super-enzymes do have limitations such as high expenses required in building large sized bioreactor and challenges in collecting existing plastic waste in landfills and oceans. Nevertheless, with sufficient fundings and research, plastic-eating enzymes will play a vital role to combat the increasing problem of plastic pollutions.

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The applications and limitations of 3D printed housing

Words by Daniel Foo (Year 11)

Chemistry

Introduction

In 2021, the Australian census revealed that over 122,000 people were homeless, a figure expected to rise. This rise of homelessness can be attributed to the rising cost of living and the lack of affordable housing, as labour costs climb higher. 3D printing technology has gotten to a point in which entire houses can be built completely out of concrete, such as Figure 1. 3D printed housing has many applications, such as its increased speed, reduced costs and labour, as well as many limitations regarding its introduction into the Australian housing market, such as its concerning structural strength.

Chemical background

3D printers are being used to build home walls, eliminating the need for traditional brick or timber laying and replacing it with concrete. Companies such as 'Contour3D' and 'Oasis Building Group' are pioneering this technology in Australia. The printer can access 3D computer files of pre-designed homes, allowing companies to fulfil custom home requests with ease. Once the large rig is set up in the build zone, shown in Figure 2, the machine prints a layer of concrete ejected from the nozzle that wraps around the entire perimeter of a home before starting the next layer, shown in Figure 3.

Rather than conventional concrete, a special type of concrete called 3D printing concrete (3DPC) is used. When compared, 3DPC has many quirks that boost its efficiency in the printing world compared to regular concrete, most notably its pumpability, extrudability, and buildability. 3DPC has to be durable enough to support its own shape and additional layers on top, whilst also being fluid enough to avoid clogging in hoses, pumps, and nozzles, and to allow smooth flow out into the wall system, as shown in Figure 4.

Figure 1: An example of a 3D printed home in New South Wales

Figure 2: Full rig of the Contour3D printer

Figure 3: Concrete 3D printer in action

Whilst conventional concrete is composed of cement, water, coarse aggregates and admixtures, 3DPC has to forgo some of the coarser aggregates larger than 20mm, as they risk jamming the printing nozzle, thereby increasing the concrete's extrudability. As coarse aggregates are sacrificed, material engineers have used finer sands and chemical binders, such as superplasticisers, to improve the final concrete's strength and bond strength, thereby promoting greater post-printing strength and buildability. A large difference between the two is that conventional concrete uses formwork, a type of mould, to shape and strengthen the concrete before use in the home. 3DPC does not utilise this method due to its layer-by-layer approach, which is a significant limitation of the material explored later.

Applications of 3D printed housing

In a world where homes are inaccessible to a large majority of the population, 3D-printed housing offers many benefits, including speed, cost, and reduced labour demands. One of the largest benefits to 3D printed housing is its speed. Whilst a traditional 22m^2 one-storey house made of timber and bricks would take a team of builders around 4-6 months to complete, 3D printers offer to complete the same task in only 12 weeks. In regional New South Wales, Dubbo Regional Council has been a strong advocate for the adoption of 3D-printed housing. As technology continues to improve, some companies have even suggested that houses could be completed in only a few days. This reduced time to build also comes with a slew of benefits, most notably lower costs. Considering the speed of the project, up to 50 per cent faster in some projects, the price for the consumer would be expected to decrease by a substantial amount. The cost of materials has also decreased for homes built using 3D printing technology, as concrete is used to the exact amount, with little to no material waste, resulting in lower overall costs. In a traditional home, the entire wall system would require 5 different crews of unique skill sets. Now, this can be replaced by a single crew and a single robot, significantly reducing labour costs. This is also helping to combat severe labour shortages, as the number of apprentices entering the workforce has steadily decreased. With 3D-printed housing, many manual labour positions can be forgone, freeing resources to allocate elsewhere while still fulfilling jobs that would not be accomplished without the workforce.

Figure 4: Example of 3D printing nozzle

Figure 5: Exterior cracks in 3D printed structure

Limitation of a faster build time

The considerable time difference between building a traditional timber-and-brick home raises some scepticism about the long-term durability of a structure built by 3D printing, particularly its structural integrity. To save the most time, some houses are built without the framework found in traditional homes, instead supporting themselves layer by layer. This process makes it extremely susceptible to plastic shrinkage cracking, which are surface cracks in set concrete formed during the period when concrete is still plastic, as the name suggests. By the time the first layer of concrete is placed, it may have dried, preventing the concrete layers from properly bonding and potentially compromising structural integrity. Air gaps prevent full bonding. This sentiment regarding the concrete is echoed by a question about the paradoxical nature of the material: something that needs to flow smoothly from a nozzle yet harden into a material capable of withstanding the elements for decades. Appealing to both target goals for a material commonly results in neither being accomplished to a satisfactory level. As time goes on, some buildings made using the technology, such as the toilet in Dubbo built in July of 2023, have already begun to show exterior cracks by December, shown in Figure 5. Many Dubbo locals question whether this risk of critical damage is worth the faster build times.

Conclusion

As demand for affordable housing in Australia increases, so does the need for 3D-printed housing. 3D printed housing provides people with alternative housing that is cheaper due to its overall cheaper cost to build, thanks to faster build times and reduced wastage, as well as less labour being required. However, with such a reduced time for building comes many shortcomings of the technology in the current day, such as strength concerns.

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Applications and limitations of sodium batteries compared to lithium batteries

Words by Henry Fan (Year 11)

Chemistry

Sodium batteries were a finalist in the IUPAC top 10 emerging technologies in chemistry in 2022. Sodium is the fourth most abundant element in the earth's crust, making it more affordable than commonly used lithium, which is facing a world-wide shortage. For decades lithium batteries have dominated the industry, however concerns with the current supply of lithium and the need for cheaper, more sustainable materials has led to an increase in research regarding sodium-based batteries. This report investigates the SHE concepts of applications and limitations, focussing on the present and future applications and limitations of sodium batteries and their broader relationship with society.

Batteries produce electricity by converting chemical energy into electrical energy. A battery consists of an electrolyte solution, an anode and a cathode. For a sodium battery to produce an electrical current, the sodium anode has to undergo oxidation, where it loses its one valence electron, which then flows through an electrolyte solution. The electron is received by the cathode, which gains the electron in a reaction called reduction. This pair of reactions is collectively known as a redox reaction (Figures 1 and 2). Lithium and sodium are both alkali metals in period one, with one valence electron. Having a single valence electron allows the element to lose electrons easily, making oxidation simpler and ensuring a more stable supply of electricity and more reliable electrical flow. Alkali metals with more electron shells less suitable for use in batteries compared to sodium or lithium because they have worse life cycles and are much more reactive. Although lithium can store more energy, sodium has advantages over lithium when used in batteries because it is more electropositive. Sodium has more electron shells than lithium, and so its valence electron is further from the nucleus, having less ionisation energy. These properties make sodium the ideal element to use as the anode in batteries.

According to Investing.com, Lithium prices in 2026 are estimated to be $11,000 USD per tonne for Lithium carbonate and $12,500 USD per tonne for lithium hydroxide, which are the 2 primarily used compounds of lithium found in batteries. However, industrial buyers may see prices in the range of $2,100 to $2,500 USD per metric ton of sodium, which translates to only a few dollars per kilogram. Sodium clearly is the cheaper of the two, and the two functionally play the same role with the same results (even slightly more efficient with sodium). Cheaper manufacturing costs for batteries lead

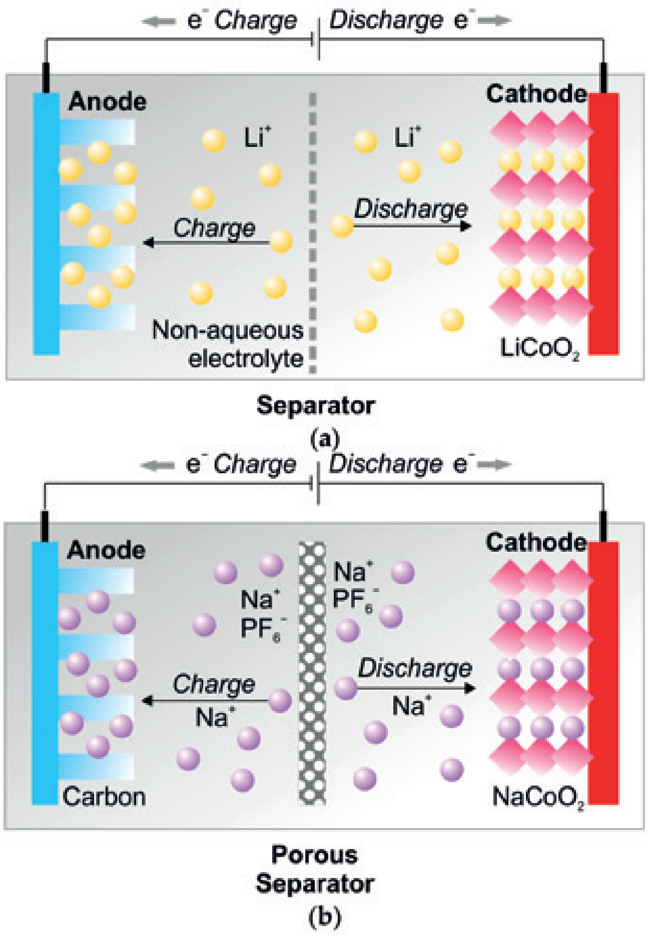

Figure 1: Comparison between sodium and lithium batteries

to many appliances becoming more affordable for society, such as solar panels, electronics and automotives. In remote regions or regions with unstable electricity grids, low-cost batteries used in solar panels can provide a stable supply of electricity to schools, hospitals and schools. The supply of sodium is far more abundant than that of lithium, being found in many common compounds such as salt (NaCl) or sodium nitrate ($NaNO_3$) and making up between 2.3% - 2.8% of the earth's crust. Coversely, lithium is in just a few regions across the world: Australia, China, Chile and Argentina. A decrease in supply from just one of these countries would cause global price spikes and disruptions in many country's economies. Through the use of sodium batteries instead of lithium, the abundance of sodium across the world would significantly lower the risk of price spikes and instability regarding lithium. With an abundance in batteries, more countries could adopt battery powered solutions, including emergency backups, electricity and transport, increasing the living conditions of many people in impoverished and rural areas.

Lithium as an element is much lighter than sodium, and much more energy dense. Lithium's energy density is 100-300 Wh/kg[6],

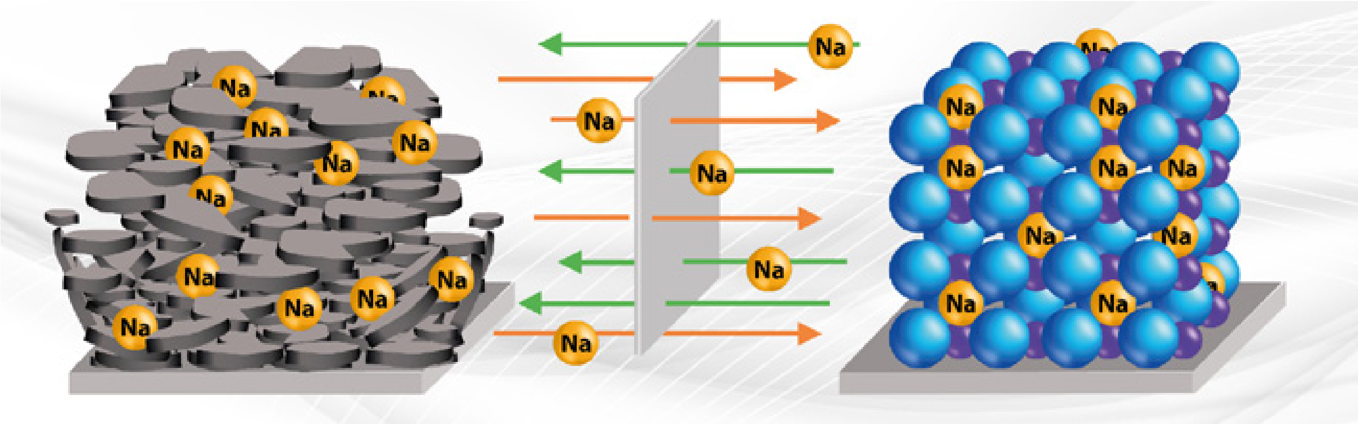

Figure 2: Example of a sodium cell

while sodium's energy density is 100-160 Wh/kg[6]. Lithium's light weight allows it allows devices to be much lighter, portable and smaller compared to with sodium batteries. Its higher energy density allows it to store more power in a compact space, enabling electric vehicles or electric devices to go long periods without needing to be recharged. Energy dense batteries allow electric vehicles to go further compared to gasoline powered ones, reducing pollution and reliance on fossil fuels. This also means that users can save money by needing to recharge their vehicles less frequently, increasing their quality of life. Sodium batteries also have shorter life cycles than lithium, only having a cycle life of 5000 cycles, compared to lithium's 8000-10,000. A higher cycle life means that lithium batteries do not have to be replaced as often as sodium batteries. This can save consumers money, who spend less often on replacements, letting them have more financial freedom. Fewer replacements also mean that fewer batteries need to be produced, meaning less demand to mine lithium and less damage to the environment.

Sodium batteries are a promising new technology that has been investigated in this report, being compared to lithium batteries. Sodium batteries are very similar to their lithium counterparts but are different in a few key areas. They are presented as a much cheaper, more abundant and more environmentally friendly alternative to lithium batteries. Lithium is lighter, more energy dense and has more life cycles than sodium, being the industry standard for batteries. The development of sodium batteries in the near future will include testing new sodium compounds to increase its energy density, and new carbon-based anode materials, which will improve cycle life and electrical efficiency within the battery.

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What is this?

Find out what the scanning electron microscope sees on page 73.

Optimising cookies: a data driven report into cookie creation and preferences

Words by Henry Yang (Year 12)

Chemistry

Introduction

Cookies can be so much more than just a sweet treat. They can be a divine indulgence, a little something to take the edge off after a long day. Hence, it is ever so important to find the "best" cookie recipe, one that is reliable, tasty but not overly fattening. This investigation explores the impact of changing certain ingredients on cookie taste and texture as well as aims to identify the preferred cookie flavour in young adolescents.

The impact of cookies on mental health

Society is creating its own problems, resulting an increase in anxiety and stress embedded in everyday life. Here, rests the importance of finding our own ways to deal and to protect our mental health. Research conducted into the effects of positive mood enhancement by Turner et al in 2010, found that cookies can be used as a mood regulation tool. A chocolate cookie can help to reduce stress leading to temporary reduced blood pressure levels. This is because the digestion of carbohydrates releases L-tryptophan which is an essential amino acid that stimulates the production of serotonin. Serotonin is a neurotransmitter that plays an integral part in regulating behaviour, mood and memory. An increase in serotonin will increase the strength and duration of signalling across the synapse which will promote healthy thoughts and decrease stress levels. However, an overreliance into the use of cookies for stress and anxiety relief can result in diabetes and fat gain. Hence, this report aims to maximise cookie flavour to personal preference while also highlighting caloric values.

Environmental and safety considerations

Society is entering into a new age that has a focus of sustainability. The preservation of Earth's natural climate is becoming a priority. This report ensures that all food produced was not wasted and ensured baking occurred during sunlight hours to make use of renewable energy sources such as solar power. Cooking and baking surfaces were wiped thoroughly, and hands were washed to ensure no bacterial contamination were present within the cookies. Any participants who tasted cookies were asked for allergies and a list of ingredients were provided in cases of uncertainty.

What are the favourite cookies of PAC students?

Figure 2 shows how most people score chocolate chip cookies the highest with a tied second place to brown butter and red velvet.

Figure 1: An image of red velvet cookies

A potential source of bias influencing the results could be in that some people may have allergies to the nuts in the macadamia nut cookies which could result in a score of 1. A similar scenario may also have been present in the more unique flavours such as the brown butter and red velvet. Those who have not had these cookies before may inherently score these cookies lower hence skewing the results. More specifically by following up with some participants, it is likely that those who have not tasted red velvet would rate it higher than the brown butter simply by the appeal of its name. There are still sources of uncertainty within the data, seen by the large error bars. However, there was a large sample size of 30 individuals surveyed, and so when the results were averaged it reduced the effect of the random error on the data.

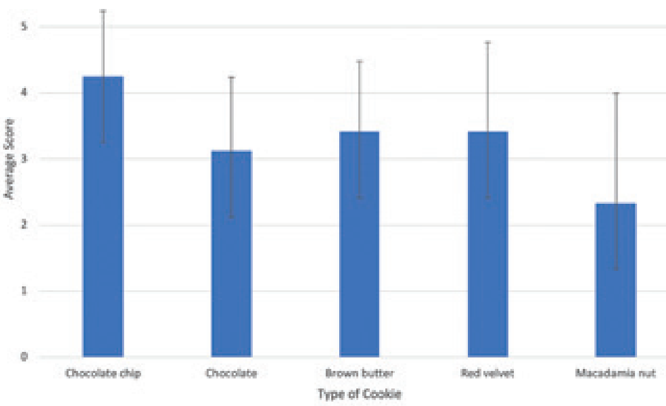

Figure 2: Average score of various different types of cookies, with error bars showing standard deviation

Another important note should be that this survey was conducted without a taste test and simply relied on the participant's recollection of their own experiences with these cookies. Therefore, those that link specific cookie flavours to happier memories are more likely to score higher. Since chocolate chip cookies are more common, it is also more likely that this is tied to an important life milestone or event leading to higher rating. This therefore, indicates that this may not be an objective rating system.

Case Studies

What is the effect of refridgerating dough?

After creating some cookie dough, half of the dough was placed in the fridge for one hour and the other half was baked immediately. This created grounds for a fair experiment and allowed a direct comparison between the two cases. Figure 3 shows minimal difference between chilling (left) and directly baking (right). It was noticed however, it was significantly easier to mold and create the cookie balls. This was because it did not stick to the hands nor the baking paper. It had minimal effect on taste or texture. Chilling the dough as a strategy would be more applicable for more sticky batters. Since, it was little effect on the taste and texture, if time permits chilling the dough will allow for easier molding and therefore shaping of the final cookie.

What is the impact of the addition of cornflour

Cornflour helps to bind ingredients together. It helps to control the spread of the cookies and therefore will harden and form the structure. This is important since, while having chewy cookies is crucial, they should also not fall apart. Figure 4 and 5 were quite flat cookies and would fall apart when picked up. Figure 6 shows a comparison between strategies such as adding and egg whites and cornflour. While both managed to maintain the structure of the cookie, the addition of the cornflour still made sure the cookies were chewy and had little impact on the flavour.

What is the Impact of varying flour amount?

The ratio of flour when baking will affect the shape, texture and colour. To investigate, two batches of cookies were produced and everything was kept same, except the chocolate used, and only the amount of flour was changed. Upon initial comparison, the shape of the cookies in Figure 5 were a lot more circular than the Figure 4. It was also a lot paler in colour. This makes sense since it would be diluting the sugar and butter in the original recipe. The ratio of brown butter to flour would be 2: 5 (Figure 5) and 3:10 (Figure 6). The brown butter flavour was slightly less intense, but the texture was a lot firmer while still being chewy. This was quite optimal so that now the cookie will not fall apart when eating it.

What is the effect of egg whites?

Two cookies were once again baked. It can be concluded that egg whites result in an increase in stability and makes the cookie fluffier. This is because egg whites are rich in protein which unravel and coagulate during baking. This helps the cookies to gain their form and stability resulting in a fluffier, soft and chewier cookie.

What is the effect of the Size of the cookie?

The size of the cookies will affect how they spread and how evenly they cook. It is important that the base of the cookie is baked through since this will directly impact if the cookies will fall apart. A larger cookie has the middle portion not properly baked. In Figure 7, the cookie on the left was made by forming 6 equal portions from the dough whereas the cookie on the right was formed through 8 equal portions. A smaller cookie baked more evenly and held it's shape better.

Figure 3: Effect of chilling dough on cookie production

Figure 4: A comparison between egg whites and cornflour

Figure 5: Cookies with 150g of flour to a brown butter recipe

Figure 6: Cookies with 200g of flour to a brown butter recipe

Figure 7: A comparison between cookies with 5cm and 9cm diameters

Recipe

Approximately 370 kcal per cookie, if 8 cookies are made from this recipe.

- 150 grams of unsalted butter (Use 180 grams and for a stronger flavour as well as a softer cookie)
- 100 grams of brown sugar
- 65 (add 50 grams for a milder cookie and 80 for a very sweet cookie) of white/granulated sugar
- 1 large egg
- 1/2 teaspoon of vanilla extract
- 175 grams of all-purpose flour
- 1/4 teaspoon of baking powder
- 1/4 teaspoon of baking soda
- 1/2 teaspoon of salt
- 2 teaspoons of cornflower
- Around 100 grams of chocolate based on personal preference.

1. Brown the butter.

- First, melt the butter on medium-high heat until bubbles form.
- Then start stirring for about 3-4 minutes.
- At the first sign of any brown particles, turn off the heat and keep stirring. It should smell like caramel and nutty.
- Then transfer 110 (Use 150 if 180 was substituted earlier) grams of the brown butter into a small bowl.
- Wait around 20 minutes for the butter to cool down since it will scramble the eggs.
- To speed up this process to around 8-10 minutes stir with a spoon, else use this time to prepare and weigh out the rest of the ingredients.

2. Add the brown butter to a medium bowl with the brown sugar and granulated sugar.

3. Then, add the large egg and vanilla extract. Whisk until the colour has lightened and well combined.

4. Whisk in the baking powder, baking soda, corn flour and salt until well combined.

5. Then add the plain flour.

- Fold in the flour using a rubber spatula until just combined, being careful not overwork the dough.
- The dough should feel quite sticky and soft.

6. Add in chocolate.

- Either chocolate chip or chopped chocolate are both fine depending on personal preference.
- Leave some behind to place on the cookies later.

7. Place the batter in the fridge for around 1-2 hours.

- This will make it easier to form the cookie shapes, since it is nearly impossible to do while still sticky.

8. Preheat the oven to 180 degrees Celsius.

- The setting used is conventional heating (the icon with the two lines)

9. Form cookie balls and place them on the baking tray.

- Depending on personal preference, this recipe will form 8 equal sized cookie balls.
- Place a layer of baking paper on the baking tray and leave around 4-5 cm between each cookie.
- Then using flatten the cookie dough and add some chocolate chunks to the top of cookie dough.
- Depending on the type of chocolate used, this will form melted chocolate pools on the cookies.

10. Bake for around 11-15 minutes.

- Since, every oven is slightly different check every 2 minutes from 10 minutes onwards. The edges should be set and the middle should still be soft but will harden when cooled.
- Bake for longer to get crispier cookies.

11. The moment the cookies are out of the oven, bang the pan on the table to help deflate the cookies. Leave to cool for 5 minutes before transferring to a wire rack to cool completely.

- This ensures that the bottom of the cookie hardens.

Conclusion

This investigation found a recipe that is based on supported investigations using a preferred flavour in male adolescents. Factors such as browning butter, dough refrigeration, flour ratio, egg white addition were shown to significantly influence cookie taste and output. Although chocolate chip was favoured, it was recognised that taste is ultimately subjective and it is a unique palette shaped by memory and culture. Still, this report presents a reliable recipe that can be used to provide a window into one’s “happy place”.

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Chemical recycling: is it the solution to the most wasteful lie?

Words by Lucas Clayton (Year 9)

Chemistry

What comes to mind when you hear the word 'recycling'? For many of us, it's the thought of our plastic water bottle being infinitely and magically converted into a variety of new products, creating a more sustainable and environmentally friendly world. Sadly, despite what we have been told by governments, leaders and enterprises, this is far from today's reality. The truth is that most plastics are only recycled two to eight times before going to landfill, so the life of that plastic bottle is not infinite – it's only a few months.

Thankfully, there is a solution to this wasteful problem – chemical recycling. Whereas standard mechanical recycling sorts and shreds plastic into smaller pellets, chemical recycling processes plastic into individual molecules which can be used to build new polymer chains or converted into different substances. This means that the lifespan of recyclable plastics becomes truly infinite, like how recycling is promoted.

How does it work?

Plastics are polymers, where many individual molecules connect to form long chains, often with hundreds of chemically bonded monomers. The wide range of methods used (Figure 1) to chemically recycle plastic such as dissolution, pyrolysis, gasification, hydrothermal treatment and depolymerisation attempts to break the bonds within these chains to return the plastic to individual molecules, which can be rebuilt into new chains (and consumables). Alternatively, both the bonds within the chains and the molecules are broken to create other useful chemicals.

Before the recycling process begins, the waste is washed and automatically sorted into its different types by its properties such as size, colour, and density. It is then manually inspected to ensure that it is free of obvious contaminants and is then shredded before it is processed.

Dissolution (purification)

Dissolution is unique in the sense that it is the only process that does not break the bonds within the plastics' polymer chain, as it is instead designed to thoroughly remove its contaminants. This method involves adding the shredded plastic to a specific man-made solvent which dissolves the desired polymer within the plastic or dissolves everything but the wanted substance. When the first method is utilised, the insoluble waste is separated from the solution via filtration and numerous different processes are then undertaken to remove the polymer from the solvent such as distillation, cooling or adding an anti-solvent. This leaves behind the polymer in a fine, pure powder, which is melted and combined with other additives before it is remanufactured into new products. Goods which can be recycled via dissolution include PVC pipes, polystyrene food containers, and polyethylene packaging, which is the most common plastic globally.

Pyrolysis

When pyrolysis is utilised, the plastic waste is heated to hundreds of degrees in an oxygen free environment to create new hydrocarbon fuels. As the particles progressively heat up to these extreme temperatures, their molecules begin to intensely vibrate, which provides them with sufficient energy

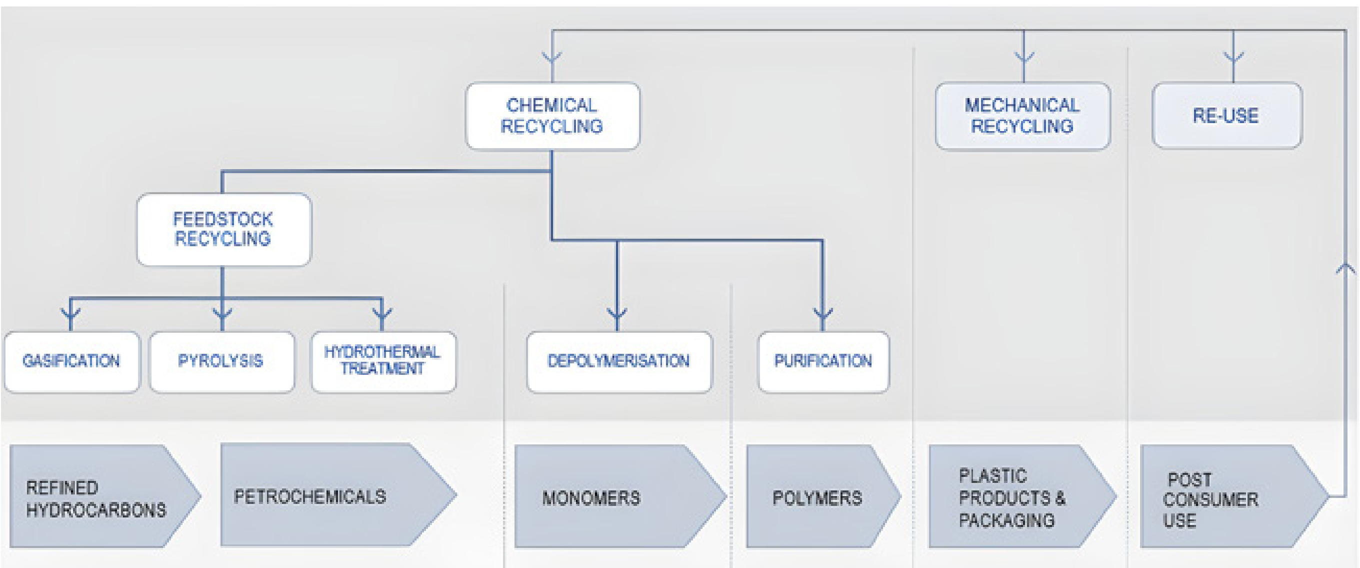

Figure 1: A summary of the products created by each recycling process and how they contribute to a circular economy

to break the chemical bonds within the larger polymer chain. It also provides the particles with enough energy to break bonds within the molecules, creating a wide range of products that change with each polymer. These substances usually vaporise due to the extreme temperature, so they can easily be directed into a nearby chamber where they are cooled and then separated. The products of the pyrolysis are primarily determined by the intensity and the duration of the heating. For example, polyethylene (C_2H_4) will often become methane (CH_4) and carbon (C) when it is heated between 250 °C and 300 °C. If the temperature exceeds 600 °C, the products will instead be acetylene (C_2H_2) and hydrogen (H_2). Pyrolysed ethylene's versatility and value are evident as methane can be used as gas for stove tops (once mixed with other additives), acetylene can be used for industrial welding, and the hydrogen can power hydrogen vehicles. Whilst pyrolysis is effective at generating desirable products, its applications are limited as only plastics such as polyethylene, polystyrene, and polybutylene can be processed.

Gasification

Gasification is essentially identical to pyrolysis, with a few key differences. Whereas pyrolysis occurs in an oxygen free environment. Controlled amounts of water and oxygen are released into the chamber throughout heating to generate the wanted products. Additionally, when the waste undergoes gasification, it is heated to well over 1000°C (rather than ~600°C) and the larger molecules are consequently broken down into much simpler chemicals, such as carbon dioxide (CO_2), carbon monoxide (CO) Nitrogen (N_2), and hydrogen (H_2), which are mixed to create syngas. Syngas is very useful and has a wide range of applications; for example, it can be converted to ammonia (NH_3) for use in fertiliser or can be added to other chemicals to produce synthetic vehicle fuels. Gasification is more frequently used than pyrolysis because all types of plastic can undergo this process; not just a select few, but it is more expensive as the material must be more intensely heated and thoroughly sorted.

Hydrothermal treatment

Hydrothermal treatment - like pyrolysis - also aims to convert plastic into a range of hydrocarbons. When plastic is hydrothermally treated, it is submerged in water under intense heat, with the ideal temperature for maximum fuel yield being about 350 °C. The material is also subject to high pressure, ranging from 2-30 MPa, depending on the type of polymer – as little as 8 MPa for PVC and as much as 22 MPa for PP. This process produces more complex hydrocarbons than the aforementioned methods, generally with over fifty molecules. The complex hydrocarbons are prevented from breaking down into simpler chemicals as the comparatively low heat and extreme pressure do not provide the particles with sufficient energy to break all chemical bonds. As a result, a wide range of complex hydrocarbons are generated, sometimes with over 50 atoms, which are used as additives to fuels at refineries. Gasses such as hydrogen and carbon dioxide are also a product of hydrothermal treatment and are usually released into the atmosphere, somewhat contradicting chemical recycling's environmentally-friendly claims.

Depolymerisation

The process of depolymerisation heats plastic and causes the polymer chain to break, leaving individual, contaminant-free monomers which can be rebuilt into new chains via methods such as addition polymerisation. When a plastic is depolymerised, it is placed in a low oxygen environment and is heated to about 500 °C. The bonds within the polymer chain break, but *most* molecular bonds within the monomers remain. The liquids and gasses which are obtained from the heating are then cooled before being distilled to isolate the desired monomer by evaporating the few contaminants, leaving the monomer behind in a powder. It is important to note that the plastic which is heated has the same chemical formula as the end product - only the bonds within the polymer chain break, not the bonds in the individual molecules. Unfortunately, there are only a few plastics which have this valuable property, such as polyurethane, so depolymerisation's use is uncommon.

Advantages of chemical recycling

The most prominent advantage of chemical recycling that initially comes to mind is that it prevents landfills from growing at unsustainable speeds and therefore reduces the amount of waste polluting the environment. This positive environmental result is due to two main reasons, the first being that, unlike mechanical recycling, the plastic's quality is not reduced with every cycle because all impurities are removed, which allows it to be infinitely reused. Secondly, chemical recycling plants can process types of plastic that cannot be treated by mechanical recycling plants, such as PVC and PS, despite accounting for a whopping 18% of global plastic consumption. The added versatility of chemical recycling to waste management would therefore save countless tons of plastic from being irresponsibly burnt or dumped into landfills annually, preserving nearby and distant environments.

The hydrocarbons created from chemical recycling allow us to artificially create a wide range of finite fuels, which will extend the life our limited resource deposits. While burning these fuels for energy does generate some harmful emissions, it is cleaner than burning pure plastic for energy as it prevents countless man-made additives from entering our atmosphere.

Disadvantages of chemical recycling

It is very easy to collect plastic and transport it to landfill. Contrastingly, collecting plastic, sorting it, heating it to over 500 °C, cooling it and then transporting the products to other facilities is terribly inefficient. In a world where energy consumption is already excessive with the AI revolution and the takeover of clean energy vehicles, this technology would greatly increase the existing burden on energy infrastructure – most methods require over 1,000 kWh of energy to recycle one tonne of plastic. This energy usage is just wasteful, especially given that the purpose of the technology is to prevent excessive consumption.

Despite the positive impacts of chemical recycling upon our environment, there are some associated negatives. The optimised man-made chemicals and antisolvents that dissolve the plastics do not occur naturally and their impacts upon our health and the environment are generally negative. For example, the common solvent tetrahydrofuran (C_4H_8O), is extremely flammable and is a carcinogen. It is therefore crucial to handle these chemicals responsibly, and whilst this is usually the case in developed nations, it is reasonable to be concerned about their impacts if our waste is mismanaged.

Additionally, the energy needed to heat the waste to such extreme temperatures and perform other processes is monumental and can directly cause an increase in emissions.

In a country like Germany where nine of the European Union's chemical recycling plants are located, roughly 45% of the energy is sourced from fossil fuels. As chemical recycling is extremely energy intensive (2,500 kWh of energy is needed per ton of plastic recycled via gasification – the same amount of energy in 30 large EV batteries), large quantities of fossil fuels are burnt to power it, releasing significant amounts of greenhouse gases into the atmosphere which work against the environment; not with it.

Operating a chemical recycling plant is not cheap. With the aforementioned 2,500 kWh of energy required to recycle one ton of plastic via gasification and 1 kWh of electricity costing roughly 33 cents, it can cost over $800 to recycle one tonne of plastic! The equipment required to recycle the material is similarly expensive, as the technology is new and complex – for example, gasification units will usually cost well over $10 million dollars. Whilst this limits the presence and the impact of chemical recycling, cost has not proven to be a major drawback for the cashed-up European countries who are the pioneers of this technology.

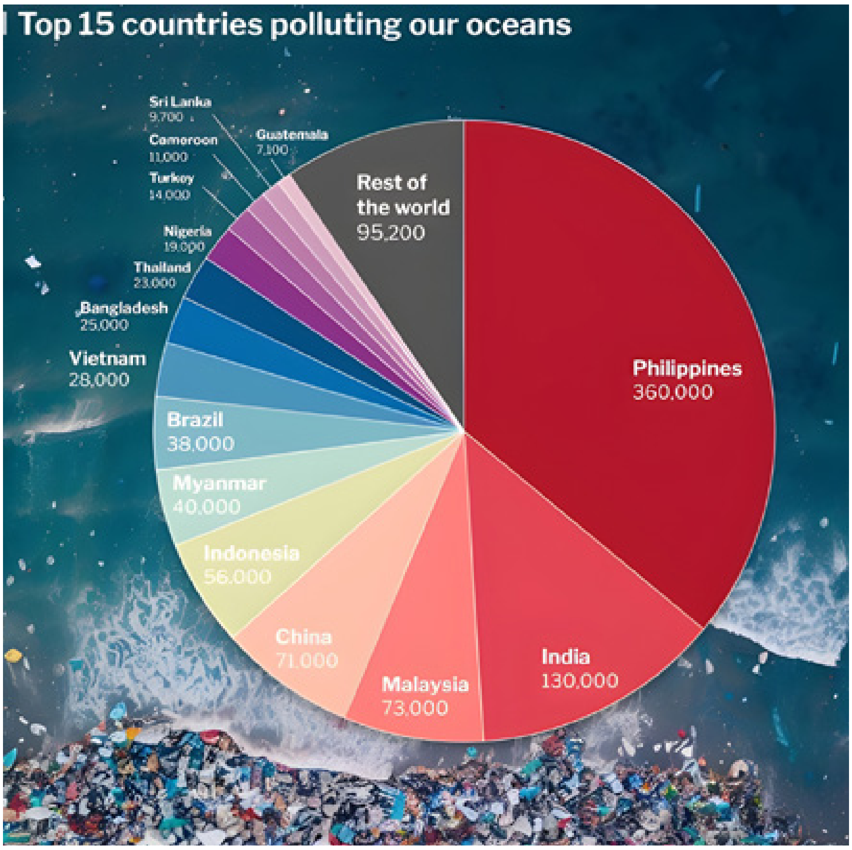

Figure 2: A graph depicting the major contributors of ocean plastics – where these chemical recycling plants need to be

Chemical recycling is promoted as a technology that eliminates huge landfills leaking into oceans and devastating ecosystems around the world. This is not the reality, as the world's 37 developed countries, where the vast majority of these facilities are located, contribute only 1% of the world's ocean plastics (mostly from littering), as they have strictly controlled landfills (Figure 2). These landfills allow virtually no plastic to escape into the nearby environment and reducing the rate at which they grow via increased recycling would therefore only prevent the tiniest amount of plastic from entering ecosystems, so we must ask the question: is chemical recycling really worth all the effort for such a small impact? However, if this technology was available to poorer nations where landfills are irresponsibly managed, then chemical recycling would definitely help prevent pollution.

Conclusion

Chemical recycling is not the solution to our plastic problem, but it will help to mitigate the impacts of our unsustainable consumption of plastics as we transition to newer, cleaner materials. If chemical waste is handled responsibly and access to clean energy is widespread, our primary priority must be exporting these technologies to developing nations such as Indonesia and the Philippines where mismanaged landfills are growing exponentially, rather than to developed nations. Unfortunately, this is not a viable solution to the plastic problem as chemical recycling is too expensive for these developing nations and is simply not important enough to gain funding which could be directed to more significant issues such as healthcare. Rather sadly, it seems that the supposed solution to the world's biggest lie, chemical recycling, is yet another lie conceived by enterprises around the world. It does not prevent overconsumption. It just provides us with an excuse to continue our wasteful ways.

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Carbon capture and storage

Words by Oliver Earle (Year 11)

Chemistry

Introduction

Carbon capture and storage (CCS) is a technocentric solution that aims to reduce atmospheric carbon dioxide concentrations through advanced engineering and scientific technologies. With a drastic increase in carbon emissions in recent decades, primarily due to human activities and global industrialisation, carbon capture and storage has been proposed as a strategy to minimize the impact of CO_2 of the environment. Carbon capture and storage is supported by scientific principles and has clear applications for mitigating knock-on effects from excess atmospheric carbon, including climate change, ocean acidification, and the overall stability of the biosphere. However, it is heavily constrained by costs, technological limitations, and energy overconsumption, preventing its implementation on a global scale. Because of this, CCS is effective to a low extent as of the present, although technological advances could make it effective to a high extent in the future.

The carbon cycle is a model describes the movement of carbon between the atmosphere, biosphere, hydrosphere, and lithosphere, as shown in Figure 1. The carbon cycle remains in equilibrium under the guidance of natural processes because the outputs of carbon into the atmosphere are offset by the inputs into carbon sinks. Alternatively, the carbon cycle's equilibrium is disrupted by human activities, such as the extraction and combustion of underground fossil fuels, which release substantial quantities of carbon dioxide into the atmosphere. This large input of carbon can not be offset by natural processes; subsequently, the biosphere suffers detrimental consequences, including climate change and ocean acidification.

Climate change occurs when greenhouse gases are abundant in the atmosphere. Greenhouse gases trap the sun's heat within the earth's atmosphere, known as the greenhouse effect. As the carbon cycle is disrupted by human activities, atmospheric carbon concentrations increase, thereby enhancing the greenhouse effect, trapping more heat and causing rising temperatures. This alters the atmospheric conditions of ecosystems, forcing organisms to either adapt rapidly or die off.

In addition, ocean acidification is a by-product of increased atmospheric carbon dioxide levels. The ocean acts as a massive carbon sink, being one of the predominant regulators of atmospheric carbon. CO_2 dissolves in water by diffusion, forming hydrogen-carbonate ions and hydrogen ions, which in turn form carbonic acid, reducing the pH of the ocean. The increased concentration of CO_2 in the atmosphere from human activities causes unnaturally high rates of carbon-oceanic diffusion, heavily impacting marine ecosystems. Over the past decade, due to rising CO_2 levels, the ocean's pH has decreased by 0.1, increasing its acidity by molluscs and corals are at the highest risk of these adversities due to the presence of calcium carbonate in their structures, which is eroded by carbonic acid, inhibiting growth rates and the distribution of these organisms.

Photosynthesis can serve as an analogy for CCS. In photosynthesis, the chlorophyll of plants traps inorganic CO_2, which is then converted to chemical energy through the presence of sunlight - explains why plant-rich forests act as the largest terrestrial carbon sink on earth. CCS is an artificial extension of photosynthesis that reduces CO_2 concentrations by capturing carbon from the atmosphere before injecting it into an underground carbon storage facility.

CCS aims to restore the carbon cycle to a stable equilibrium, where flows of carbon between sources and sinks are balanced, thereby improving ecological communities previously affected by climate change and ocean acidification. Reducing CO_2 will decrease the greenhouse effect, in an attempt to reverse global warming and return the Earth to a natural state. This will also reduce the associated impact of

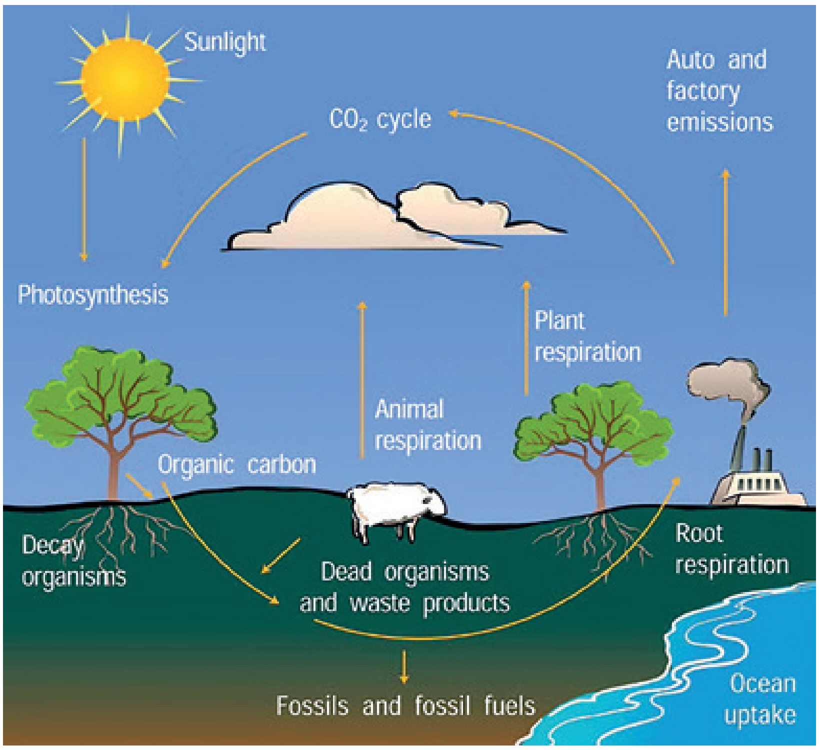


Figure 1: carbon cycle diagram

climate change, including extreme weather events such as droughts, flooding, and storms, which wreak havoc on both human and animal communities. Moreover, this will decrease the diffusion of CO_2 into the oceans, minimising the formation of carbonic acid and increasing pH. This is critical for the regeneration of marine communities, specifically molluscs and corals. Protecting these organisms will increase marine biodiversity and resilience. The overall environmental stability from reduced climate change and ocean acidification also means fewer resources and funds need to be spent on the redevelopment and preservation of ecosystems by local governments and councils. Another environmental benefit involves the use of CSS as an artificial replacement for forests. The current deforestation of the Amazon rainforest, among others, is reducing the capacity of these ecosystems to act as carbon sinks. Although not ideal, CSS has potential applications to compensate for the reduced CO_2 trapped by forests, thereby reducing environmental impacts on other ecosystems.

CCS has also been shown to have societal value in creating jobs and fostering overall economic growth. The development and implementation of CCS require expertise from multiple sectors, including engineering, construction, geology, and scientific research. Information from the Victoria State government suggests that an average of 2,707 construction jobs could be created per annum between 2026 and 2030. This creates a positive domino effect on the entire economy: more jobs = more income = more spending = more money in circulation, which strengthens the economy and leads to an economic boom.

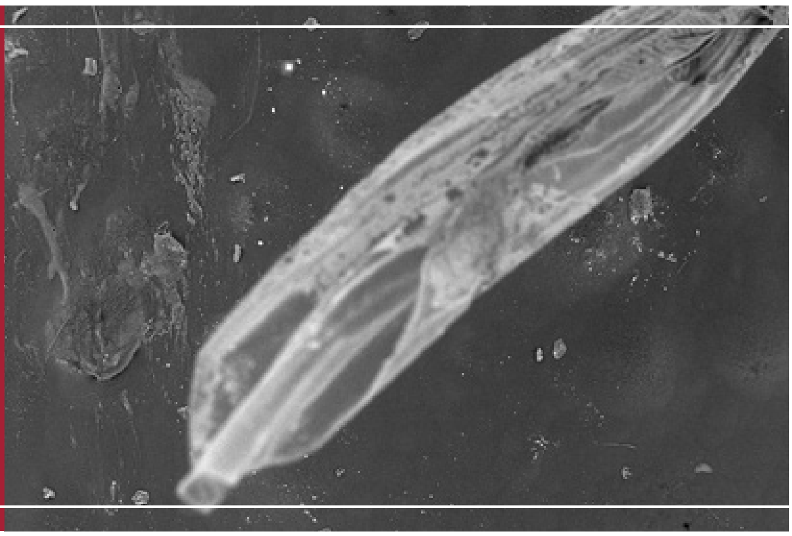
However, implementing CSS is limited by multiple factors, including costs, technological constraints, and energy overconsumption. The infrastructure required for CCS, including pipelines and underground storage facilities, is extremely expensive because it involves highly advanced technology that is not yet mass produced. An analysis by the Global CCS Institute estimated that onshore CCS plants cost approximately US$ 7 per carbon tonne captured, thereby costing US$7 billion per billion carbon tonnes. For reference, China emitted roughly 13 billion tonnes of carbon in 2025. Despite the long-term environmental and social benefits, the initial costs are far beyond the capacity of developing governments, preventing large-scale execution of CCS.

Secondly, CSS demands for constant inputs of substantial quantities of energy to operate, which is often referred to as the “energy penalty.” Due to the comparatively higher efficiency of non-renewable energy sources, CSS facilities may be forced to use non-renewable energy, partially offsetting their environmental benefits, which undermines their core purpose to mitigate the environmental damages caused by increased $C0_2$ concentrations in the atmosphere. CSS also fails to address the root cause of climate change, the reliance on fossil fuels. Instead of being a short-term solution to aid in the transition to renewable energy, it can act as an incentive for companies to burn more fossil fuels and exploit the environment to a greater degree than already done before. This reduces urgency for investment in sustainable alternatives, delaying long-term solutions to tackle climate change from its roots.

Carbon capture and storage is a technocentric solution proposed to extract and store carbon dioxide in the atmosphere underground through advanced engineering and scientific technology. This will help rebalance the carbon cycle’s outputs and inputs, which were previously unbalanced by human activities. In theory, this will positively influence ecological communities that previously faced risks from climate change and ocean acidification. In conjunction with this, CSS has recognised society’s value and its ability to drive economic growth. However, the implementation of CSS facilities is constrained by cost, technological limitations, and energy consumption, making it yet to be proven effective at a commercial scale. From this, it can be concluded that CSS is effective to a low extent right now, but with the improvements in the availability and functionality of technology, it could be effective to a great extent in the future.

What is this?

Find out what the scanning electron microscope sees on page 73.



To what extent are social, ethical and environmental considerations influencing the application of iron fertilisation in reducing atmospheric CO_2?

Words by Taine Meyer (Year 12)

Chemistry

Introduction

Large-scale iron fertilisation is a proposed solution to rising atmospheric CO_2 levels. Iron's ability to stimulate photosynthesis and enhance carbon sequestration offers potential relief in the ongoing climate crisis, yet research and real-world examples highlight the risk that accompany it. Elevated production of neurotoxins such as domoic acid in phytoplankton pose a significant threat to the balance of marine ecosystems and the livelihood of coastal populations, undermining confidence in its safety and feasibility. These concerns are reinforced by the strict legal frameworks and international treaties which regulate geoengineering and the manipulation of natural systems, limiting the development of iron fertilisation as a legitimate and sustainable climate strategy.

Chemical background

Large-scale iron fertilisation relies on the chemistry of iron (II) sulfate, which is a commonly used iron source in phytoplankton growth when in a soluble compound of ferrous sulfate heptahydrate ($Fe_2SO_4 7H_2O$). It is favoured in fertilisation as when exposed to sea water, ferrous iron, Fe^{2+}, is more soluble than ferric iron, Fe^{3+}. Yet, once exposed to an aqueous environment, Fe^{2+} still rapidly oxidises to Fe^{3+}, reacting with the oxygen-rich ocean surface as O_2 present acts as an oxidising agent.

$$4Fe^{2+}\,(aq) \rightarrow 4Fe^{3+}\,(aq) + 4e^-$$

$$O_2\,(g) + 4H^+\,(aq) + 4e^- \rightarrow 2H_2O\,(l)$$

This creates the following redox reaction:

$$4Fe^{2+}\,(aq) + O_2\,(g) + 4H^+\,(aq) \rightarrow 4Fe^{3+}\,(aq) + 2H_2O\,(l)$$

Once Fe^{3+} is produced, it forms insoluble $Fe(OH)_3$ as it immediately hydrolyses in water.

$$Fe^{3+}\,(aq) + 3H_2O\,(l) \rightarrow Fe(OH)_3\,(s) + 3H^+\,(aq)$$

Multiplying this hydrolysis reaction by 4 is required to match the $4Fe^{3+}$ produced.

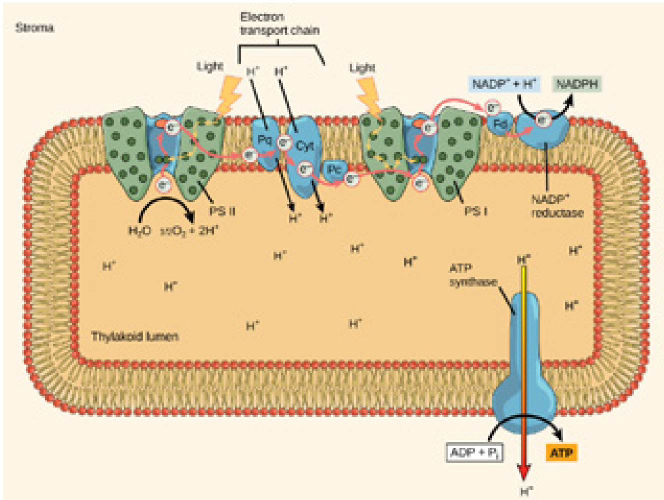


Figure 1: Electron transport chain in photosynthesis

$$4Fe^{3+}\,(aq) + 12H_2O\,(l) \rightarrow 4Fe(OH)_3\,(s) + 12H^+\,(aq)$$

Combined with the previous redox reaction, the net reaction of these two processes is

$$4Fe^{2+}\,(aq) + O_2\,(g) + 10H_2O\,(l) \rightarrow 4Fe(OH)_3\,(s) + 8H^+\,(aq)$$

The precipitate of $4Fe(OH)_3$ denotes that Fe^{2+} has a very short residence time in surface water, therefore only a small fraction of unreacted iron remains available for phytoplankton to absorb. Thus, repeated additions of iron are needed in the fertilisation process to maintain a sufficient level of iron concentration.

When absorbed by phytoplankton, particularly in high nutrient low chlorophyll regions (HNLC) where photosynthetic reactions are restricted by iron scarcity, iron functions as a limiting reagent. This is because iron is incorporated into redox centres of iron–sulfur (Fe–S) clusters and heme sites present within phytoplankton, which act as redox centres. These redox centres perform a sequence of redox reactions which function as a photosynthetic electron-transport chain. This chain permits electrons to travel through molecules capable of cycling between oxidation states, and in doing so it drives the movement and the release of H^+ ions as these ions need to remain chemically balanced as shown in Figure 1. An example of the formation of H^+ ions is through water oxidation in the lumen, located in the chloroplast of eukaryotic organisms such as phytoplankton. This is the endpoint of the electron transport chain (ETC) where protons accumulate, represented by the equation and Figure 1.

$$2H_2O\,(l) \rightarrow O_2\,(g) + 4H^+\,(aq) + 4e^-$$

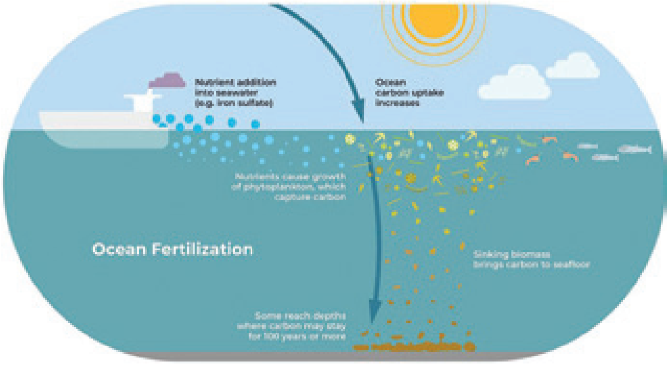


Figure 2: Ocean fertilization

The accumulated H^+ is then used alongside electrons to reduce $NADP^+$ (nicotinamide adenine dinucleotide phosphate) located in the stroma of phytoplankton to produce NADPH.

$$NADP^+ (aq) + 2e^- + H^+ (aq) \rightarrow NADPH (aq)$$

NADPH accelerates the rate at which light-independent reactions of photosynthesis (the Calvin cycle) can convert CO_2 from the atmosphere into carbohydrates, therefore creating an increase of organic carbon stored within the phytoplankton.

$$CO_2 (g) + H_2O (l) \rightarrow CH_2O (l) + O_2 (g)$$

The carbon is sequestered through the biological carbon pump, a natural process which transports carbon from the organic matter of phytoplankton into the deep ocean (Figure 2). It is here where carbon remains isolated from the atmosphere, either stored in ocean sediments, such as $CaCO_3$, or left within deep waters which are largely immiscible with the surface due to density differences within the water.

Solutions, discoveries, and impact evaluation in iron fertilisation

The application of experimental iron fertilisation has required scientists to evaluate the economic, social, cultural, and environmental impacts of increased phytoplankton growth. Global carbon dioxide emissions have increased by more than 69% since 1990, as current trajectory threatens to breach the 2015 Paris Agreement (Figure 3). This poses the risk of global warming surpassing the 1.5°C agreed maximum, communicating the demand for sustaining climate strategies.

Researchers believe that 7-9 billion tonnes of carbon dioxide must be sustainably removed per year to hit climate targets, numbers exceeding current CDR (Carbon Dioxide Removal) of only 2 billion tonnes. This places greater emphasis on the need for large-scale iron fertilisation, with the potential to remove approximately one billion tonnes of carbon annually alone.

Experiments comparing the effectiveness of phytoplankton carbon intake in iron-rich and iron-poor HNLC regions found that carbon export was 'two to three times larger' in iron-fertilised regions, demonstrating that the addition of iron unleashes phytoplankton growth that otherwise cannot occur, accelerating the biological carbon pump and thus enhancing long-term carbon sequestration

However, experimental iron fertilisation in HNLC regions has also revealed long-term constraints on biodiversity and ecosystem sustainability, casting doubt on its potential as a large-scale climate solution. Ocean enrichment experiments have shown that iron additions stimulate the growth of the toxigenic diatom genus Pseudonitzschia, a single-celled photosynthetic plankton which produces domoic acid (DA), a potent neurotoxin (Figure 4).

Domoic acid, and repeated exposure to it, poses considerable risk to marine biodiversity. The neurotoxin can cause reproductive failure and increased mortality in most ocean organisms, disrupting food-chain hierarchies. In 2025, cetacean mortalities in California rose to record-breaking levels, as upwards of 100 long-beaked common dolphins were reported dead or dying. This is in relation to America's western coast experiencing premature algal blooms, intensifying the presence of domoic acid in waters. Evidently, this has the possibility to shift entire ecosystems toward a less resilient, less productive state, making habitats increasingly vulnerable to broader habitat degradation.

Social, ethical and environmental considerations influencing the acceptance of iron fertilisation

Iron fertilisation's ecological risks raise the need to monitor its social and ethical implications, assessing whether it is a viable sustainable climate mitigation tool. As per the 1975 London Convention, and later 1997 London Protocol, marine geoengineering is defined as the 'deliberate intervention in the marine environment to manipulate natural processes, including to counteract anthropogenic climate change and/

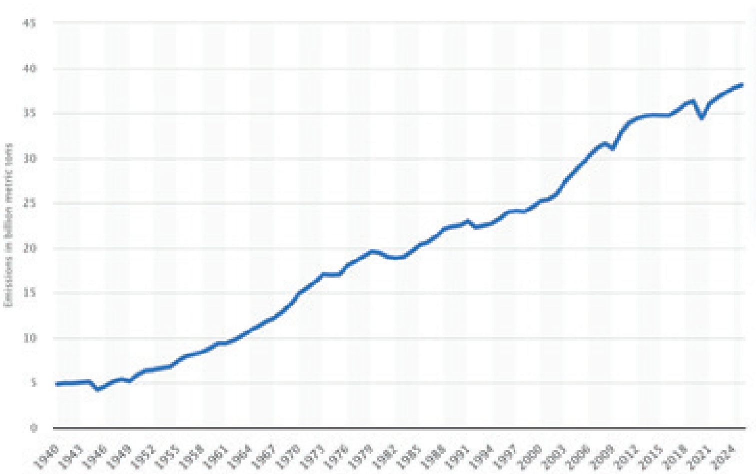


Figure 3: Global carbon emissions

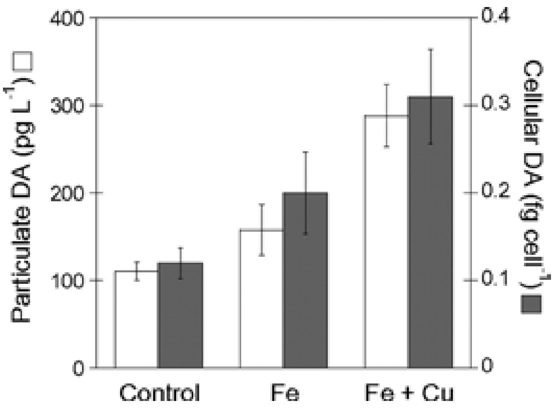


Figure 4: Comparison of particulate and cellular domoic acid concentrations

Figure 5: Red tide

or its impacts. Under these international treaties, large-scale fertilisation and its use to accelerate phytoplankton growth are prohibited, following precautionary principle that the social and ethical risks outweigh the potential climate benefits (Figure 5).

In Australia, iron fertilisation is banned under the 1981 Environment Protection (Sea Dumping) Act, aiming to 'control all sources of marine pollution'. This follows the nation's aim to bar all forms of ocean geoengineering since 2013, advocating for an amendment to the London Protocol.

Furthermore, the impact of iron fertilisation and its ability to create harmful blooms has raised public concern in protecting both food and income security. Approximately 3 billion people rely on wild-caught and farmed seafood as a primary source of protein, a population put in jeopardy when toxic algal blooms contaminate fisheries. For example, in 2015, local fisheries on the West Coast of the U.S. lost over an estimated $100 million USD due to algal damages, conveying how sensitive coastal economies are to change in plankton communities.

Compared to alternative carbon sequestration methods, iron fertilisation's increased susceptibility to environmental and ethical damages has limited its acceptance. Unlike iron fertilisation, artificial upwelling aims to mimic natural nutrient cycling by pumping nutrient-rich deep ocean water to the surface, removing the addition of foreign substances (Figure 6). This restricts the creation of domoic acid and hypoxic ocean 'dead zones', conserving aquatic ecosystems and maintaining balance within the seafood industry. Moreover, iron fertilisation is relatively expensive in comparison to other sequestration methods, costing between $80-457 per tonne of CO_2 removed, whereas artificial upwelling, between $100-150. This influences economies away from iron fertilisation as an acceptable climate solution, bounded to price restrictions and environmental impact trade-offs.

Future endeavours

Future pathways for large-scale iron fertilisation remain uncertain, as emerging scientific evidence highlight both its potential effectiveness and its limitations. Ongoing projects such as the NOAA Ocean Acidification Program are conducting simulation experiments across the Southern Ocean, Equatorial Pacific and Subarctic Pacific, evaluating the effectiveness of iron enrichment in capturing CO_2 using 'ocean gliders' (Figure 7).

Furthermore, the use of organic ligands are being implemented as a safer alternative to existing iron fertilisers to

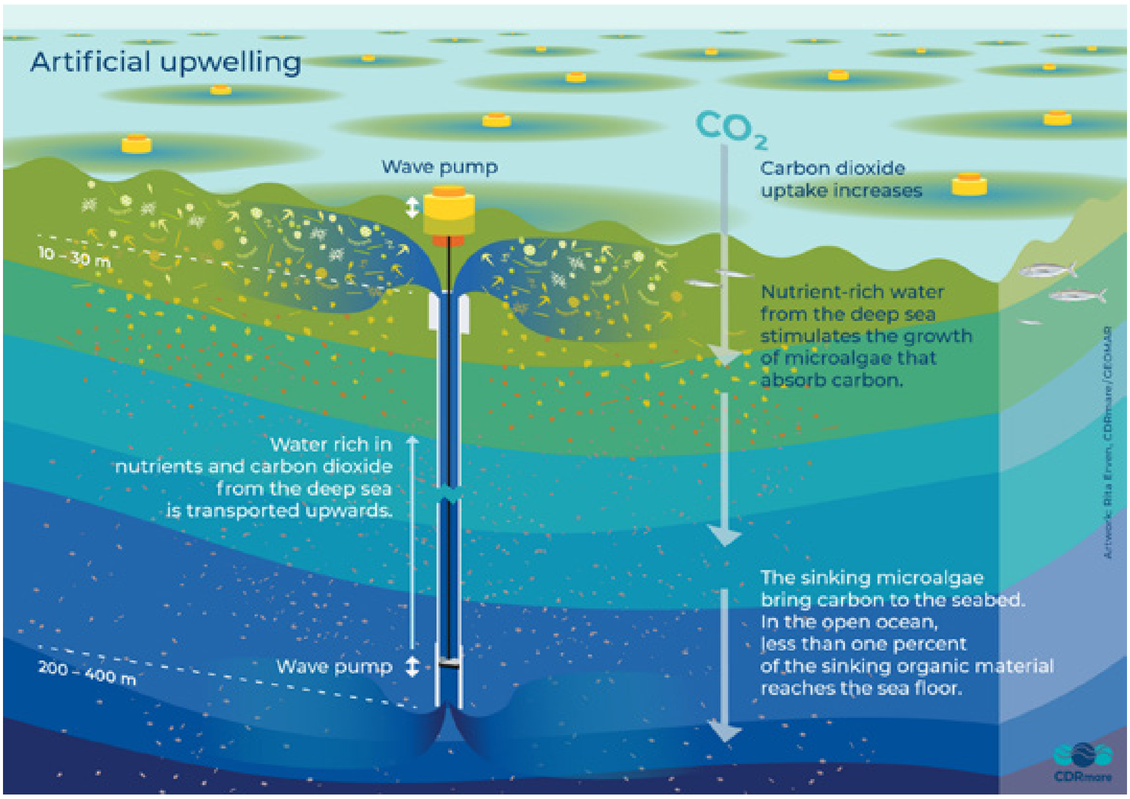


Figure 6: Artificial upwelling

slow the release of Fe^{3+} in instantaneous dumping. Although initial trialling has shown promise, amendments to the London Protocol in 2013 have introduced stricter guidelines for any future fertilisation trials. This establishes the standard that long-term ecological reliability must be demonstrated before fertilisation can be considered as a viable climate strategy.

Conclusion

While its ability to increase photosynthetic carbon uptake demonstrates clear chemical and environmental applications, large-scale iron fertilisation and its underlying ecological risks highlight limitations to its practical use. The presence of toxic algal blooms and the threat it poses to coastal economies influence public iron fertilisation's acceptance and legislative policy, creating necessary caution for its future development. Principally, iron fertilisation conveys the broader challenge of balancing innovative scientific solution with global responsibilities, as scientists continue to strive for sustained climate action.

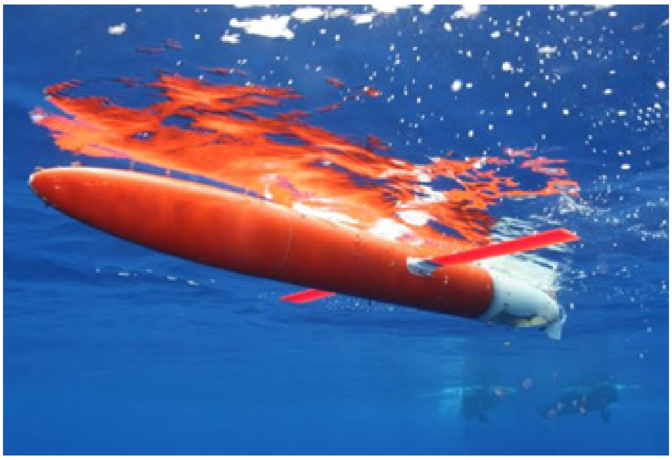


Figure 7: Spray-glider

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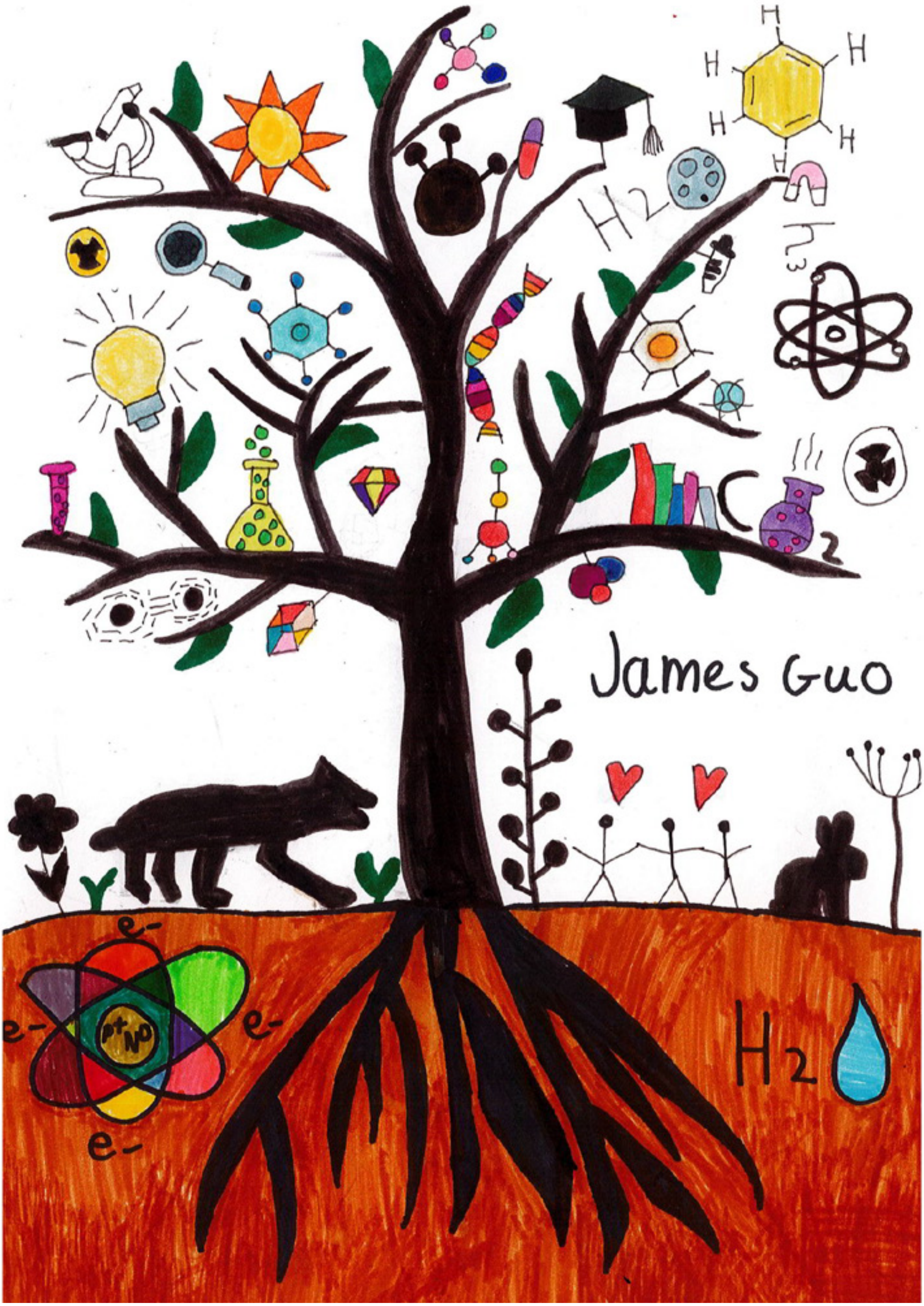

Tree of Science by James Guo (Year 5)

My artwork shows how chemistry powers our planet. The tree shows the growth of science and the branches connect the Tree of Science with life and chemistry.

Is LiDAR-based collision detection safer than camera-only systems?

Words by Ashton Lim (Year 11)

Physics

Introduction

This investigation will explore light detection and ranging (LiDAR) in car systems. When compared to the normal camera-only systems, LiDAR provides a much more protective upside. Despite camera-only systems being effective at displaying real-time footage of the car's surroundings, they don't measure distance, depth or velocity. This means that the automatic braking system in the car cannot be as accurate when compared to a car equipped with LiDAR technology. With the advancement of artificial intelligence and autonomous driving, the lack of precision that camera-only systems provide creates unnecessary risks for the passengers, whereas with LiDAR technology, more accurate distances are recorded, allowing the car to brake earlier and hence reducing the force applied to the passengers.

Relevant physics concepts

When investigating the effects of LiDAR, the physics concepts of Newton's first law, momentum, and inertia will determine its effectiveness. This is because collision detection systems rely on these key physics concepts to calculate the optimal and safest braking distance. Newton's first law states that an object will remain in its motion or at rest unless an unbalanced force acts upon it. In context, any car will remain at a constant speed unless the brakes are applied. Which is why LiDAR detection systems are much more effective than camera-only systems. By calculating the distance to other road users, it determines the appropriate amount of force to apply to stop the car. Furthermore, when looking at the equation of momentum of where is mass and is velocity, when the car has a higher velocity, it obtains more momentum which requires more force to stop. This means that using LiDAR to accurately measure the distance to another car will calculate the optimal time to reduce the car's speed based on the speed of the car ahead. This will ultimately reduce the car's momentum making it easier for the car to stop and hence safer for the passengers. Finally, when looking at the equation of where is force, is time, and is the change in momentum. By LiDAR's capability to reduce the car's momentum, the change in its final and initial momentum decreases, and by reducing the car's momentum, the amount of time taken to stop the car decreases. When applying this

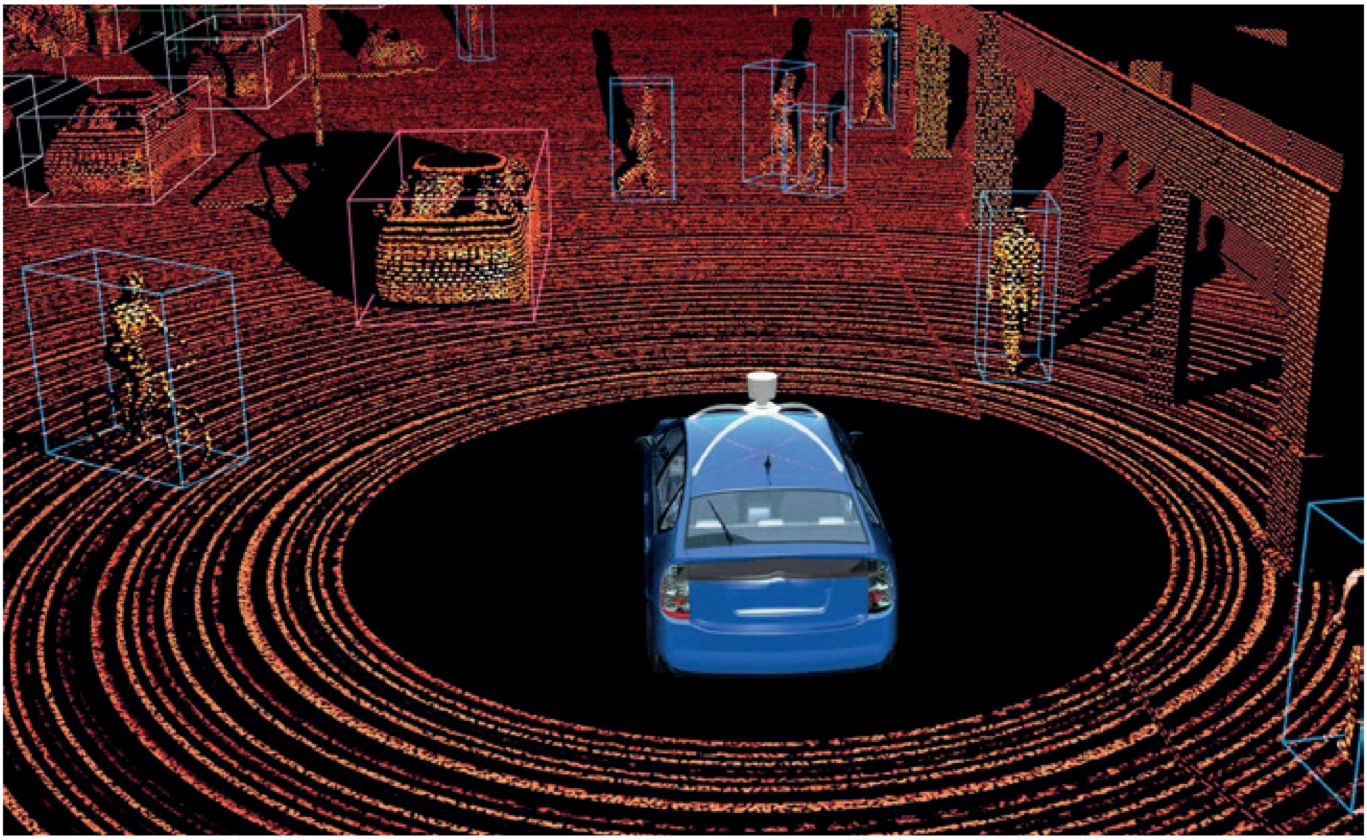

Figure 1: LiDAR imaging of a car's surrounding

to the equation, the resultant force is lower. In the context of passenger safety, the force the passenger experiences when stopping the car is reduced, making it safer.

The applications of LiDAR technology in collision detection systems in automative vehicles

The application of LiDAR technology in cars is its ability to create highly accurate 3D maps of the car's surrounding through its ability to direct and measure light pulses that reflect off its surroundings. This enables the car to react to obstacles on the road in real time and react safely.

Firstly, due to most LiDAR technology in cars using lasers of 1550nm wavelength (YellowScan, 2025), it is invisible to the naked eye and harmless to the human eye. This wavelength also allows for a reading up to 350m, allowing for a detailed map (see figure 1) that provides the car with extensive time to react and understand the road conditions ahead, like roadworks, winding roads, pedestrian crossings, etc. Furthermore, by using lasers to detect the car's surroundings and a scanner to group the points, a 3D scan of its surroundings is created. This enables the vehicle to react accordingly and understand the road's obstacles. Continuing, LiDAR technology is not affected by light, as its 3D imaging is created using lasers. Allowing for LiDAR technology to be capable of working effectively and safely at any time.

Lastly, because thousands of lasers are fired every millisecond, the scans can be used to accurately predict the velocity of surrounding cars, which allows the car's overall driving system to understand the optimal speed, distance, etc., the car should be travelling at.

Essentially, this shows how scientific knowledge enables LiDAR technology to enable the car to make real-time judgments based on accurate, reliable data, helping reduce the severity and likelihood of collisions. Highlighting how knowledge of light and motion has been adapted by engineers to improve technologies that improve safety standards on our roads. It also highlights the continual modification of the system based on data collected through extensive testing. This is shared with relevant parties, reviewed, and then applied in the development and/or modification of systems, which will, in turn, benefit society. With the number of vehicles on roads increasing, the importance of driver, occupant, and pedestrian safety is becoming an issue, and media coverage and any changes regarding safety are welcomed by the public. Media plays an important part as well, and it is important that the public is fully informed about how manufacturers, along with government legislation, are helping to protect everyone using roads and adjoining pathways.

The limitations of LiDAR technology in collision detection systems in automative vehicles

While Lidar has the potential to improve safety, there are concerns about what could happen if the system fails or works incorrectly, and the dangers to the public in such situations. These ethical concerns do affect the trust people have in autonomous vehicles. This lack of trust could affect decisions about purchasing an autonomous vehicle. Costs raise other ethical questions, as only wealthy people can afford to purchase an autonomous vehicle, suggesting inequality. Firstly, LiDAR, despite being reliable for most situations, can produce confusing, unreliable maps when faced with dark objects or clustered entities. Since LiDAR uses lasers to identify objects, when a dark object is present, it can absorb the laser instead of reflecting it back to the sensor for detection. Hence, creating blind spots and spots of vulnerability, resulting in the automotive vehicle not fully understanding the nature of its surroundings. Furthermore, when a cluster of bodies is present, the outline presented to the scanner may be confusing, preventing the scanner from separating the objects as distinct entities and grouping them as one, which can cause the vehicle to believe there are fewer vehicles on the road. Continuing, when faced with heavy precipitation, LiDAR is susceptible to producing an incomplete map, as the lasers are reflected off particles in the air rather than off actual road components. This forces manufacturers to implement or develop specific approaches to address this environmental issue, increasing costs for both manufacturers and customers. Finally, the economic stress that LiDAR imposes on manufacturers can lead to a scarcity of availability. As vehicles require multiple sensors per car, this drives up costs, leading to higher maintenance and ultimately limiting consumer access. Fundamentally, these limitations in LiDAR technology show that, despite showing significant applications, it cannot be a direct replacement for a camera-only collision detection system.

Conclusion

In conclusion, LiDAR-based detection systems offer significant advantages in early obstacle detection, accuracy, and depth perception, allowing the vehicle to reduce its momentum and kinetic energy in time before impact, thereby reducing the risk of fatal injury to passengers. However, these applications are held back by limitations in their ability to identify and map specific anomalies, and their financial constraints also create a barrier to LiDAR technology being fully implemented in automotive vehicles. While LiDAR technology offers a more advanced and safer approach to vehicle automation, certain circumstances limit its incorporation into automotive vehicles. It also raises ethical and economic challenges that must be addressed before acceptance.

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Limitations and future development of ion propulsion

Words by Darcy Sandow (Year 11)

Physics

Introduction

Unlike traditional chemical rocket engines, ion engines use electrical fields to accelerate charged particles, greatly increasing the efficiency of spacecraft. This allows acceleration for months on end, allowing the rockets to achieve extremely high speeds across great distances. This report explores the limitations of ion engines, and the future development combatting the aforementioned issues.

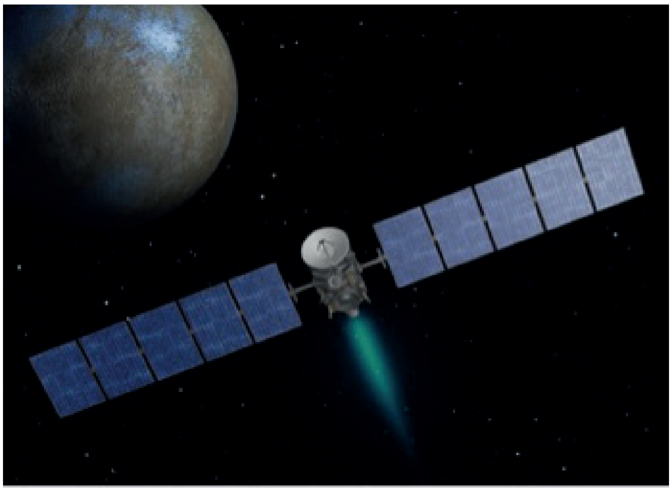
Physics background

Ion engines work by accelerating ions to great speeds (up to $43kms^{-1}$) and ejecting them in the opposite direction of the desired thrust. For this acceleration to be achieved, ions must first be created. This is commonly performed by stripping atoms of electrons via electron bombardment. This process involved an electron colliding with a propellant atom with neutral charge. This collision releases electrons from the atom, creating a cation, a positively charged ion. These ions are affected by electrical and magnetic fields. Thus, they can be accelerated by the spacecraft. As these ions carry mass, they carry momentum. The law of conservation of momentum states that in a closed system, the amount of momentum remains constant and cannot be created nor destroyed but only transferred through the effect of forces. Thus, the spacecraft gains momentum equal in magnitude but opposite in direction to the ejected ions. Noble gases are often used as propellant; this is because they don't need special handling or storage procedures as they are inert and don't react. Xenon is the most common gas used; however, argon and krypton can also be substituted.

Ion thrusters are unique as they have an extremely efficient specific impulse, often defined as the ratio between mass used and change in velocity (ΔV). This makes them ideal for long term space missions.

Limitations of ion propulsion

Ion propulsion, while having extremely high specific impulse, has two main drawbacks; energy requirements and low thrust. This results in extreme difficulty applying this technology to missions further out in the solar system, or manned missions. Additionally, ion engines are extremely electrically demanding. As xenon fuel has no chemically stored energy, the spacecraft must provide all energy in the form of electricity. The current method for supplying this electrical energy is solar panels. However, this creates multiple problems. The Dawn spacecraft's ion engines needed 2500 watts of electricity to

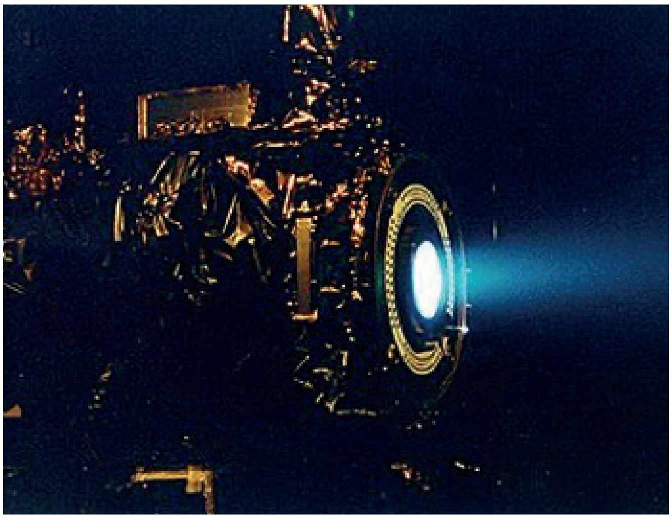


Artistic rendering of the Dawn spacecraft

effectively propel its 700kg mass. A craft similar in weight to the *Space Shuttle's Orbiter*, roughly 100 times the mass at 70 tons would thus need a power output of 250 kilowatts of power. The current largest orbital solar array, the *ISS Solar Array* produces 120 kilowatts of power. Even ignoring the cost and difficulty in installing gigantic solar panels, they can simply not deliver enough power for a proportionally scaled ion engine craft, limiting the technology to lightweight, unmanned probes. Electrical demand becomes an even greater issue when venturing farther out into the solar system, as solar panels become exponentially less effective. Previous deep-space missions, such as the voyager spacecraft, have used the radioactive decay of Plutonium-238 for power. However the output of these generators, called radioisotope power systems (RTGs), diminish over time. This limits the prolonged use of ion engines to the inner solar system. Furthermore, ion engines have extremely low thrust. NASA's dawn spacecraft had 92 millinewtons of thrust, a force similar in magnitude to the weight of a sheet of paper. Thrust this low results in missions often lasting years with engines active for months. While this prolonged mission time is often beneficial for probes, it makes manned applications of ion engines extremely difficult. The limitations of ion propulsion systems highlight the need to find solutions through science to improve the efficiency and power of this technology.

Development of ion propulsion

Ion propulsion technology has continued to advanced. The concurrent research has highlighted the progress in scientific understanding as the field continues to evolve. This is being revolutionised by the development of Nuclear Electric Propulsion (NEP) technology. This technology promises to fix may of the issues presented by scaling convectional ion propulsion. NEP technology works via utilising a nuclear fission reactor to power a large ion engine. The first interplanetary



NSTAR ion engine test in 1999

NEP craft, NASA's *Space Reactor 1 Freedom,* has been announced for launch towards Mars in 2028. It offers mass transport solutions beyond the effective range of solar panels.

Similar to RTGs mentioned earlier, NEP uses nuclear fuel to generate electricity. However, in NEP spacecraft use nuclear fission reactors like those on Earth. The difference here is the passive nuclear decay and thus limited power output of RTGs, in comparison to fission reactors which use controlled fission. The first use of nuclear reactors in space was upon the System for Nuclear Auxiliary Power (SNAP) 10A in 1965. The craft operated using enriched uranium fuel and was able to operate for 43 days generating of 600 watts of electricity before failure elsewhere in the spacecraft. The SNAP project was able to test the feasibility of nuclear reactors in space.

In the 1992 NASA announced a new program, the Nuclear Electric Propulsion Spaceflight Test Program. This was the first considerable action taken towards the development of NEP technology, with two Russian Topaz-2 reactors being purchased for testing. However, due to budget cuts, this program was cancelled the following year.

Conceptual rendering of space reactor 1 freedom

Despite these setbacks and years of prolonged study, in March of 2026 NASA announced a new program, involving the aforementioned *Space Reactor-1*. The proposed spacecraft will generate 20 kilowatts of energy and will deploy a payload of *Ingenuity* helicopters. As the spacecraft in early in development, specific details are unknown. However, the implications of *SR-1 Freedom* for the future of space travel may be great. This is because the constant, if minimal, thrust ion engines provide may make the trip to Mars shorter. Ultimately, this would result with NEP technology being the standard for interplanetary voyages.

Additionally, research into alternatives to conventional ion thrusters which use xenon has addressed factors such as reducing costs, improving thrust to power ratios and deeper space travel. Startup companies such as ThrustMe in France have contributed resources into investigating and developing iodine as an alternative propellant which, if successful, will greatly save costs as it more abundant than xenon. This highlights how science is being used to continue to refine and improve technology through innovation and research. The ongoing research across all areas of ion propulsion will enable faster travel through space through more efficient spacecraft. This would enable space exploration and allow the possible colonisation of Mars in the near future, the development of infrastructure on the Moon in addition to providing a greater understanding of space and our place in the universe.

Conclusion

Ion engines will not make chemical rockets redundant, as they are near useless within the atmosphere and during launch. However, in the vacuum of space, ion propulsion offers a unique alternative to chemical rockets as they can accelerate for extended durations while using very little fuel. If developments in nuclear electric and iodine propulsion persist, it is likely ion engines will be humanity's ticket to the Solar System and beyond; possible only through human effort and curiosity.

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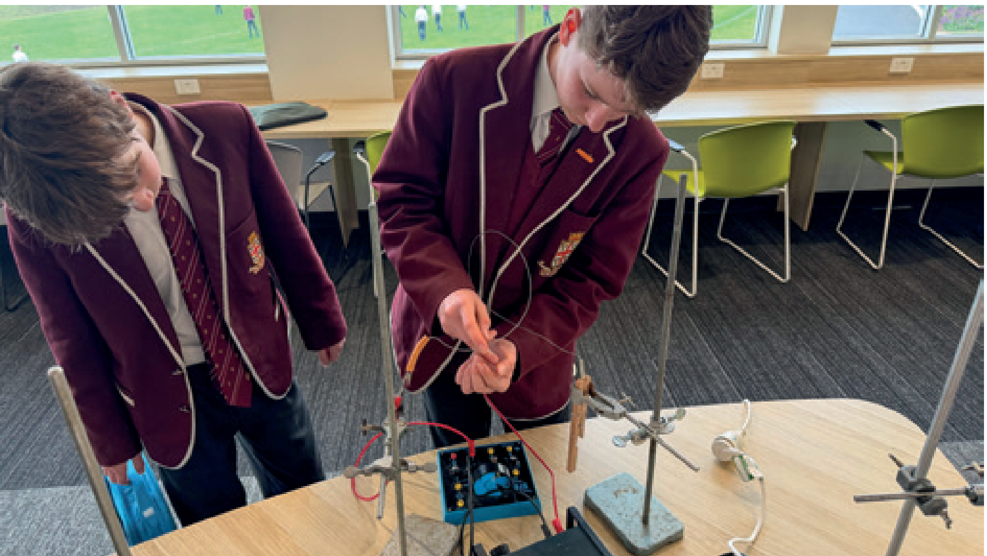


A brief timeline of our universe

Words by Minul Jayasinghe Arachchi (Year 8)

Physics

The universe started almost 14 billion years ago, so to some it may seem impossible to know what really happened. However, there are some ways that scientists have found the way the whole universe began. The most recognizable start of the universe is the theory of the Big Bang, which explains how there was an infinitely hot, dense and small point called a singularity. From there it began to rapidly grow due to thermal expansion and soon became what we now know as the universe.

The first thought of this event first was noted by the German priest Georges Lemaitre (Figure 1) in the early 20th century. Like many theorists that were proposed at the time, Lemaitre was met with large amounts of scepticism due to his theory stating a singular beginning and smuggling religious theories into his own, even being told by Einstein "Your math is correct, but your physics is abominable". But this didn't suppress George. He continued to study his theory on a 'primeval atom' where they had undergone some sort of 'super-radiation', causing the matter to be constantly expanding and decaying into smaller atoms, further continuing to expand the universe. He continued to work on his theory until he sadly passed in 1966, but not until he had explained the formation of galaxies, cosmic rays and cosmological constants.

The Big Bang marked the start of the universe's life however from there it took almost no time before something new happened (Figure 2). Soon the singularity began to expand in an undecillionth of a second. A few seconds later, majority of all the antimatter that once existed was annihilated due to a slight asymmetric property of the universe. Eventually protons and neutrons began to fuse to create the first atoms which were mostly hydrogen and helium. Around 50 thousand years later, the amount of matter formed had overtaken the amount of radiation in the universe. Nothing much would happen until around 100 million years after the Big Bang. The matter formed large gas clouds before combining and making the first stars and eventually galaxies. After around 9 billion years, stars begin to 'die' in large explosions called supernovae, which are the ideal conditions to form specific elements like oxygen, carbon, iron, silicon etc, which are all crucial elements for life.

Figure 1: Portrait of Lemaitre

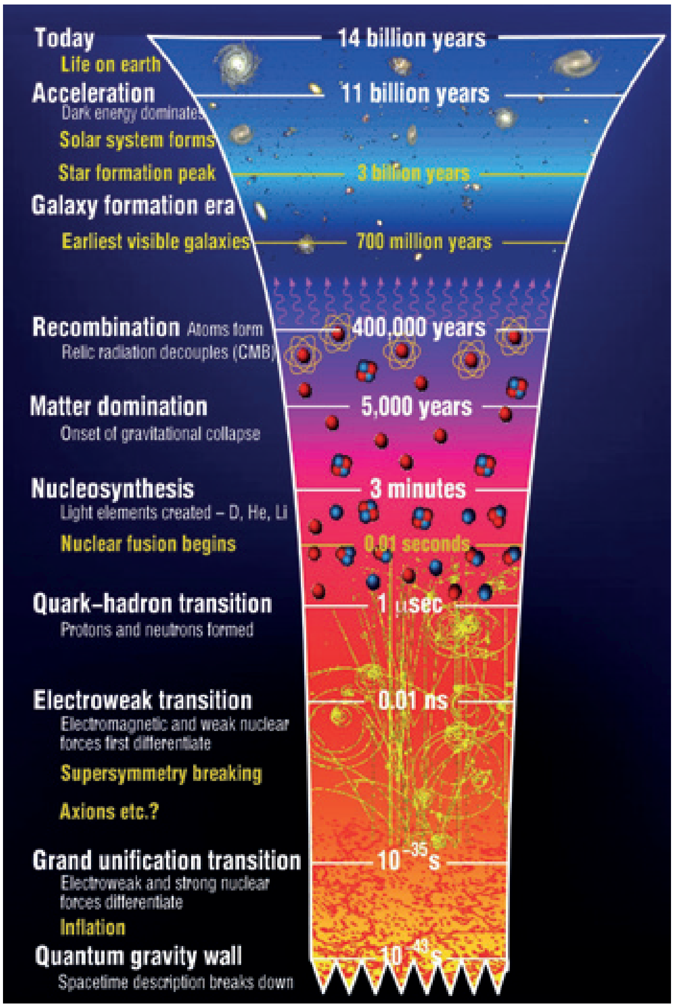

Figure 2: Universe timeline

Our Solar System

Eventually, approximately 4.6 billion years from the present, only a large cloud of gas and dust formed the end of a solar nebula that eventually flattened into a thin disk. Majority of matter that was left was pulled into the centre before igniting and creating the sun. Any gas that was close to the sun was pulled in, leaving behind heavier and metallic materials, creating the terrestrial planets, while the lighter gasses further away that didn't get pulled into the sun further became the outer gas planets (Figure 3).

100 million years later, the earth was finally formed to a form but was just a molten sphere of magma. Around 10-100 million years later a solid crust had formed. Approximately 300 million years later, through gravity, the earth was able to trap water vapor from the atmosphere before everything eventually precipitated into water due to the continued cooling of the planet. However, the core stayed molten due to the slower crystallisation of the iron.

Oceans were the starting place for life. With ideas ranging from lightning strikes to life coming from extraterrestrial locations, the exact reason for life's original creation is still in question. Regardless of origin, early single-celled life was born. Around 2.4 billion years from the present, the 'Great Oxygenation Event' occurred where cyanobacteria massively populated the Earth creating more oxygen in the atmosphere that paved the way for more complex life forms that would need more oxygen to thrive. After around 900 million years, multi-cellular life forms called eukaryotes appeared. Cambrian explosion occurred another 1 billion years later. Around 475 million years ago, the original plants began to colonise the continents of the Earth, and around 110 million years ago the first animals moved out of the ocean and onto the land.

This point in time is when many amphibians and reptiles evolved and began to live in the swamps of the land, which all became fossil fuels for the present. After the Permian Extinction which wiped out majority of all life in the oceans, dinosaurs finally began to emerge onto land and the first mammals took their first ever steps on Earth. At this moment in time, a huge diversification of life forms occurred which became the basis of all life forms in the modern time. After the Cretaceous-Paleogene extinction of the dinosaurs, mammals were finally able to thrive without the risk of as many predators.

From around 200,000 years ago modern humans began to evolve in Africa, and continued to colonize the Earth, and moved around the globe. Around 10,000 years ago, humans began to look similar to what they are today and the first settlements of humans and civilisations began to roam the Earth.

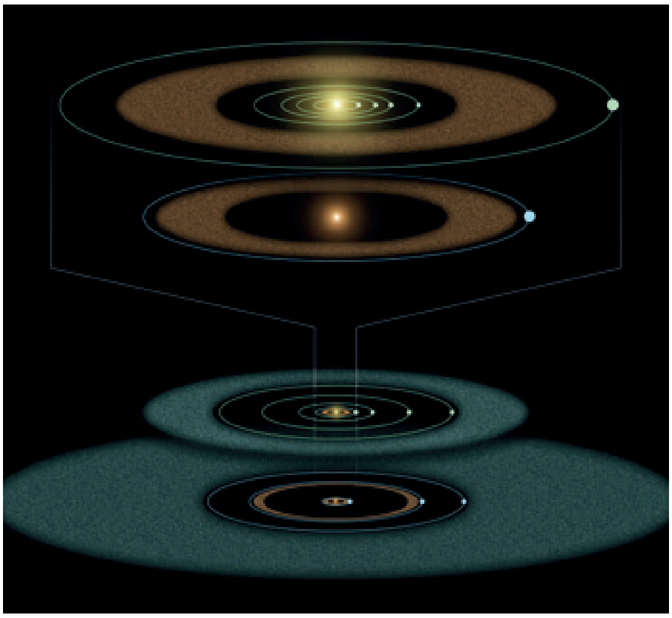

Figure 3: Solar system start

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How have historical nuclear disasters influenced the public opinion on radiation and hindered the acceptance of nuclear medicine in Australia?

Words by Saverio Blefari (Year 12)

Physics

Public attitudes towards radiation have often been shaped more by fear than by scientific understanding, leading to a hindered Australian nuclear program. This imbalance between perception and reality is evident in how nuclear disasters influence public opinion. Atomic accidents such as Chernobyl (1986) and Fukushima (2011) amplified cultural anxieties, correlating catastrophic exposures to the carefully regulated low-dose application in medical imaging. Yet, this same technology underpins life-saving applications in nuclear medicine. This highlights how nuclear disasters influence public opinion.

Radiation is a fundamental concept in physics, describing the emission of energy as electromagnetic waves or energetic particles from unstable atomic nuclei. This process is called radioactive decay, where unstable isotopes spontaneously transform into more stable nuclei, releasing energy. The rate of decay is called half-life, the time required for half of a radioactive sample to decay. For example, isotopes such as Technetium-99m are ideal for nuclear medicine, as its half-life is approximately 6 hours, allowing practical imaging without prolonged retention in the body. This is called gamma decay, in which a high-energy photon is emitted from an unstable nucleus in an excited state as a gamma particle.

$$ {}^{99\mathrm{m}}_{43}\mathrm{Tc} \longrightarrow {}^{99}_{43}\mathrm{Tc} + \gamma $$

However, in Australia, there is only one facility responsible for the production and distribution of nuclear medicine isotopes: the Australian Nuclear Science and Technology Organisation in Lucas Heights, Sydney. This plant specialises in creating Technetium-99m by decaying Molybdenum-99. This occurs through decay, where a neutron in an unstable nucleus transforms into a proton, emitting an electron and an antineutrino.

$$ {}^{99}_{42}\mathrm{Mo} \longrightarrow {}^{99\mathrm{m}}_{43}\mathrm{Tc} + {}^{0}_{-1}\mathrm{e} + \overline{\nu} $$

The influence of public perception on nuclear medicine is profound. Nuclear accidents, Hiroshima and Chernobyl, created widespread fear of radiation, a fear later termed radiophobia. Radiophobia has also resulted in a variety of counterproductive behaviours and policies, from a mother being afraid to hug her child after an X-ray to 1600 premature deaths to the disruption of medical care after the Fukushima accident. This overreaction demonstrates how radiophobia can cause greater harm than radiation itself, as seen in premature deaths from unnecessary evacuations and medical disruptions, a clear case of fear, not exposure, endangering lives. This misunderstanding is further illustrated by comparing everyday radiation doses (Figure 1), showing that standard medical procedures expose people to less radiation than natural background levels. Yet, these small doses often provoke disproportionate fear, demonstrating how perception, rather than actual risk, shapes public attitudes toward nuclear technology. This fear has shaped politics, with governments hesitant to invest in nuclear energy despite Australia holding 28% of the world's uranium and having no commercial reactors due to legislation . This limits Australia's supply of the radioisotopes required for nuclear medicine, forcing reliance on vulnerable overseas supply chains. This problem is compounded by the short half-lives of many medical isotopes, such as the technetium-99m with a half-life of 6 hours. Therefore, these isotopes cannot be stockpiled and must be produced and delivered quickly, making a constant supply in Australia for diagnostic imaging and cancer treatment difficult.

Furthermore, research commissioned by Liberals Against Nuclear discovered that abandoning the nuclear energy policy could boost the Liberal Party's primary vote by 2.8 percentage points. Furthermore, many news outlets claim that nuclear power may have cost the coalition up to 11 seats in the federal election. This exemplifies how public perception of nuclear technology can shape democratic outcomes. However, it must be noted that the Liberal loss stemmed more from public disapproval of policy decisions than from nuclear policy alone. Moreover, public concern over nuclear power was also informed by price, specifically after the CSIRO released a report stating that, by 2040, the cost of nuclear energy is projected to range between $145 and $238 per megawatt-hour. In contrast, solar and wind power are expected to cost significantly less, at $22–$53 and $45–$78 per megawatt-hour respectively. In this way, radiophobia extends beyond the clinic, constraining both medical innovation and national

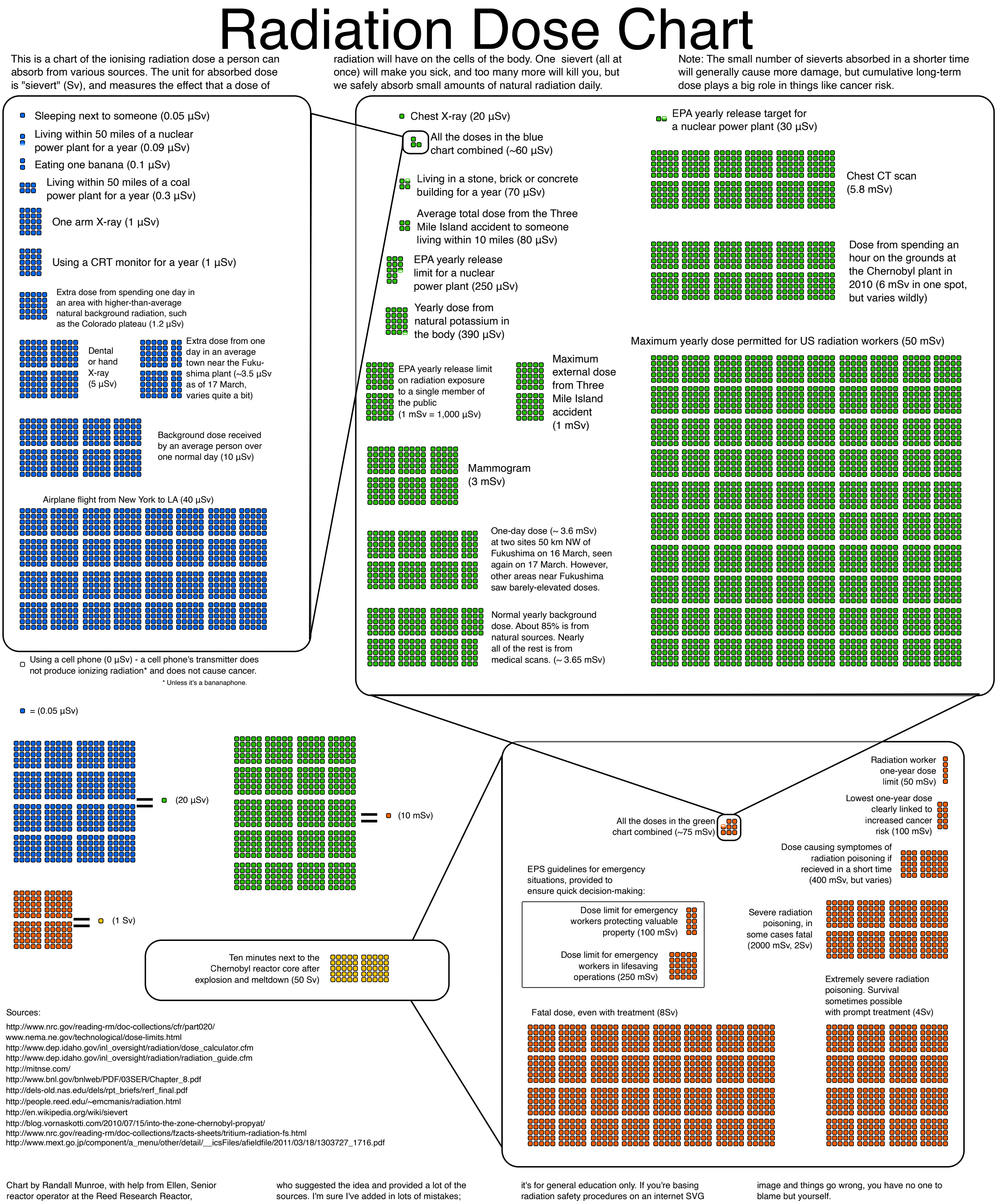

Figure 1: Radiation dose charge

energy policy. Overall, the stigma surrounding radiation is not accurate, as scientific evidence shows that the doses used in medical imaging and treatment are astronomically low and controlled. Yet the low acceptance of this science has been strongly influenced by social and cultural fears stemming from past nuclear events, showing how public perception can shape policy and limit technological progress. Therefore, increasing understanding can help shift these influences to support medical advancements.

To achieve the optimistic outcome of nuclear imaging, scientists must convey complex physics concepts, such as radiation dosage, half-life, and shielding, in an accessible way to satisfy policymakers and the general public. For example, the media coverage of Fukushima and, by extension, Australian perceptions of radiation failed to distinguish between the acute radiation exposure near the reactor and the negligible doses experienced abroad. Additionally, "negligence and failure" were compounded by a lack of planning and training in accident mitigation. Collaboration between scientists, governments, and health organisations is essential to building trust. Through fellowships and joint research projects, scientists have worked closely with bodies such as the International Atomic Energy Agency. These partnerships have led to conventions on radiation safety, standardised dose measurements, and international distribution of isotopes. These efforts are supported through the IAEA's Technical Cooperation Programme with ANSTO. Due to Australia's lack of domestic reactors, such relationships are vital to the country's nuclear industry. Without effective communication and collaboration, nuclear medicine's benefits risk being overshadowed by fear.

Therefore, the safe and effective use of nuclear medicine is underpinned by radioactive decay, half-life and controlled dosage. In Australia, however, public perception shaped by global nuclear disasters has limited the nation's capacity to produce vital isotopes. This demonstrates the influence of nuclear catastrophes on attitudes, restricting scientific progress. Equally, the role of communication and collaboration is critical; only through transparent dialogue between health organisations, scientists and governments can these social norms be challenged, unlocking Australia's potential in nuclear medicine.

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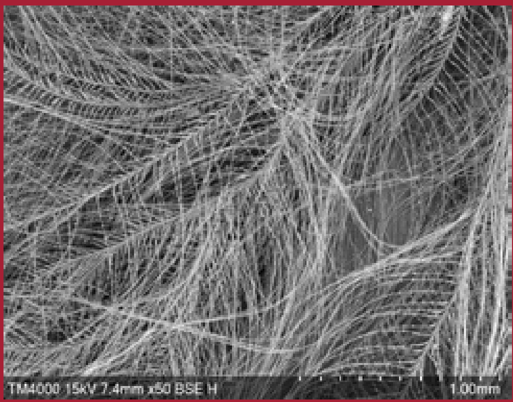
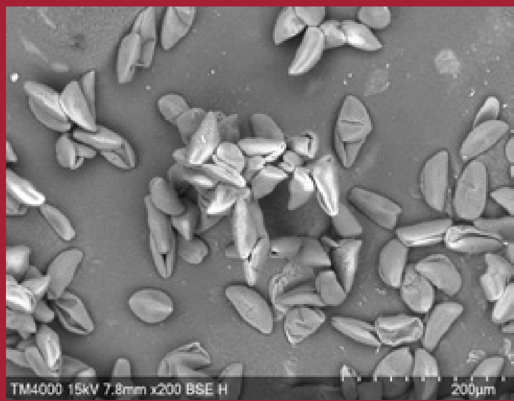
What is this? *Answers*



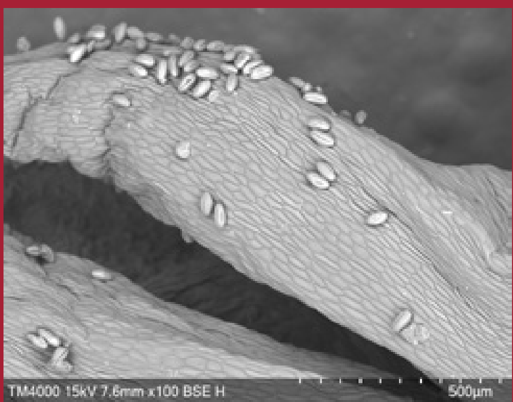
Page 5: Chicken feather (x50) by Jimmy Kammer (Year 8), Xander Kammer (Year 8), and Lochlann Sutherland (Year 8)

Page 34: Spider in web (x30) by Rayan Khan (Year 8), Miles Khouc (Year 8), and Ziggy Tasci (Year 8)

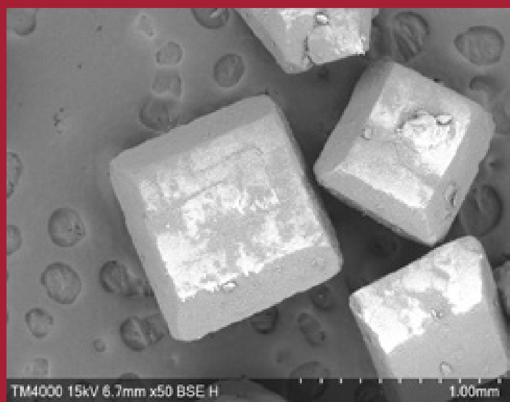
Page 8: Hair (x100) by Reuben Bosch (Year 9)



Page 41: Pollen (x200) by Judd Darley (Year 8) and Griffin de Braconier Harders (Year 8)



Page 28: Camellia pollen on stigma (x100)



Page 47: Sugar granules (x50)

Page 31: Petal (x100) by Jack Woodrow (Year 8)

Page 55: mosquito wing (x100) by Edward Colaiacovo (Year 8) and Hugh Herriot (Year 8)

Science Competition Award Winners 2026

Big Science Competition High Distinction

James Arkwright (Year 9)
Aidan Chen (Year 9)
Jonathan Chong (Year 9)
Lucas Clayton (Year 9)
Sammy Rayner (Year 8)
Leo Wu (Year 7)
Terry Yao (Year 7)

Science Olympiad High Distinction

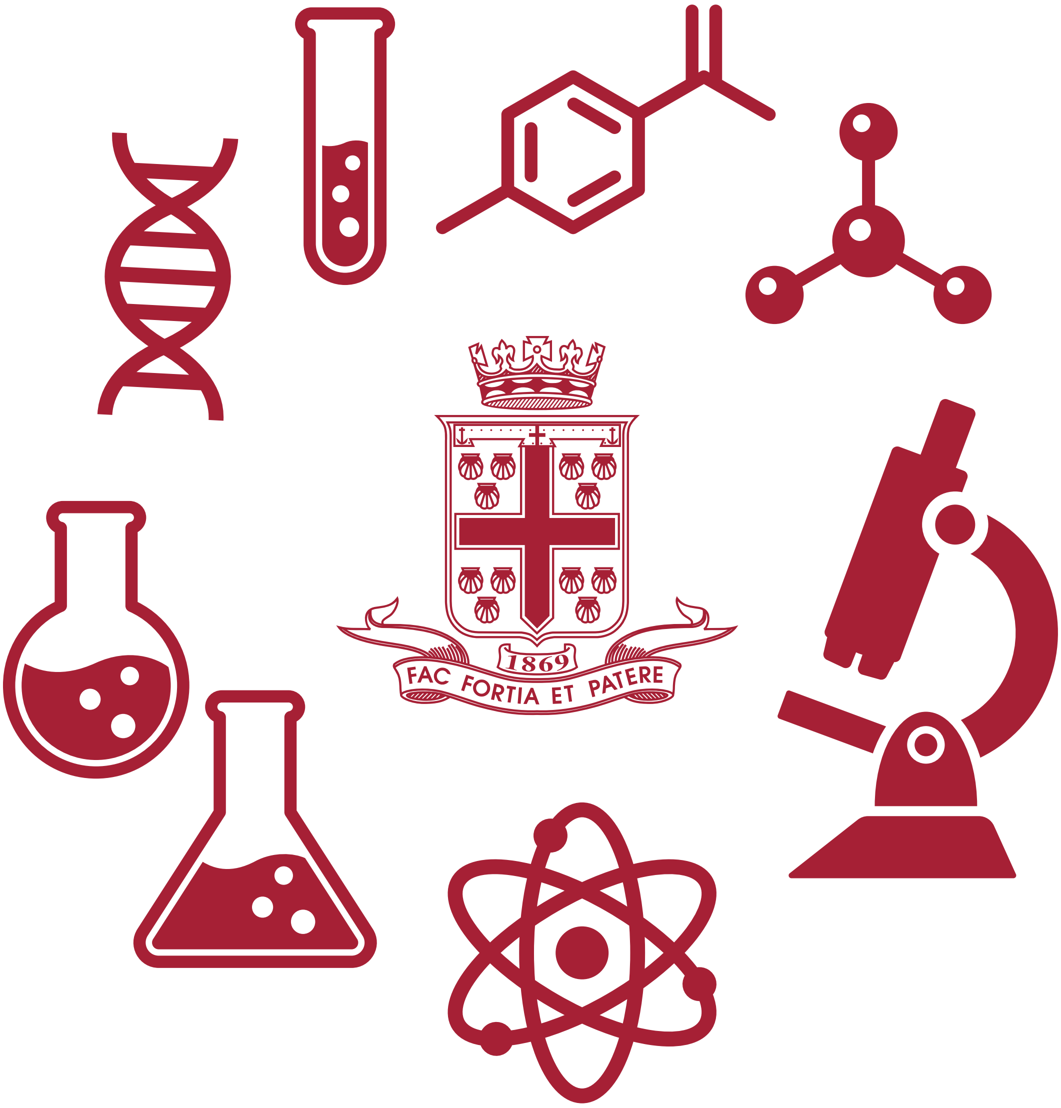
Billy Ang (Year 8)
Leo Wu (Year 7)

RACI Titration Competition Gold Standard

Alec Halkett (Year 11)
Milo Kotzee (Year 11)
Ashton Lim (Year 11)
Xavier Lim (Year 11)
Keith Ng (Year 11)
Alexander Oakes (Year 11)
Henry Reid (Year 11)
Charles Tang (Year 11)
Kaelan Virag (Year 11)

Oliphant Science Awards

Finn Gelsthorpe (Year 2)
Charles Tang (Year 11)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