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PRINCE ALFRED COLLEGE SCIENCE JOURNAL 2024

LXXX Edition

80 YEARS OF DISCOVERY



A word from the Editor

As we celebrate the launch of the 80th edition of the Prince Alfred College Science Journal, we reflect on the tremendous journey of scientific exploration and innovation in the last 8 decades through the theme *"80 years of discovery"*. This year's theme invites us to explore the rich tapestry of scientific breakthroughs, challenges and advancements that have been made since the establishment of the journal in 1945, and which continue to change, shape and enhance our understanding of the world today.

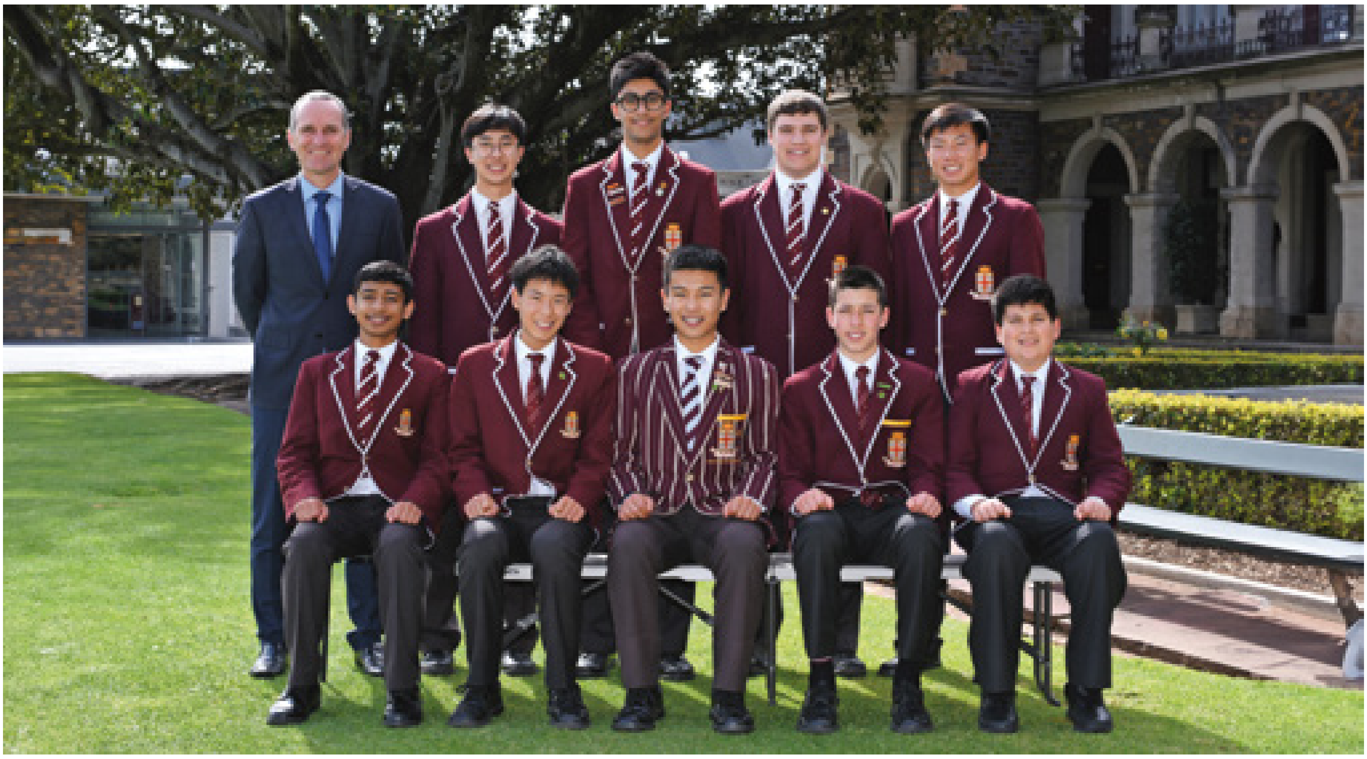
This 80th milestone is a testament not only to the longevity of this publication, but also to the enduring curiosity and fascination of generations of Prince Alfred College students, scientists, and researchers. Encapsulating scientific fields such as nuclear physics, agricultural science, and materials technology, this year's edition of the Science Journal seeks to remind us of the interconnectedness of scientific discovery, and how each new finding builds upon the foundations laid by our predecessors – much like an allegory for the annual progression of the College Science Journal itself.

The articles in this 80th iteration have been carefully curated to showcase a historical outlook of the diverse and interdisciplinary development of modern science. With authors ranging from Year 7 to 12, alongside our guest author Dr James Miller, the Science Journal provides students with an opportunity to engage in scientific research and writing, and have their work published in an official and respected format. But more than this, the Science Journal offers a unique learning experience which expands beyond the classroom, demonstrating the widespread and real-world applicability and implications of science, and this year in particular, the cumulative nature of the discovery and development of scientific knowledge throughout the past 80 years.

I would like to express my thanks to Mr Hopkins for his ongoing commitment and dedication to bringing the Journal to life every year, whether it be through helping us decide upon a theme, organising committee meetings and pizza lunches, or liaising with the printers, we really appreciate the time and effort that goes into delivering a publication such as this, and your guidance with writing, editing, and proofreading articles has been invaluable. Thank you, Aiden Lim, for designing our promotional posters as well as our front cover, which was the final product of several iterations and refinements. Thank you Dr James Miller for taking the time out of your busy schedule to contribute what is a very interesting article, and most importantly, thank you to the committee members for your diligence and enthusiasm. It certainly was an extensive process editing and narrowing down the 38 submissions we received this year, but your tireless efforts have been instrumental in the success of this year's edition of the Journal. The Science Journal ultimately is a student-led celebration of student work, and so without the committee members, this publication would not be possible.

I feel extremely honoured to expand upon the legacy of LXXX years of students in my role as Chief Editor of the Science Journal this year, and I am looking forward to seeing what the next 80 years of discovery may hold, and the involvement of Princes Men in and around these future scientific discoveries.

Caleb Tang
Chief Editor, 2024



2024 Science Journal Committee
Back Row: Mr Peter Hopkins, Aidan Foo, Aryan Parwal, Eddie Lock, Aiden Lim **Front Row:** Noah Varghese, Charles Tang, Caleb Tang (Chief Editor), Lachlan Logan, Sage Goel. **Absent:** Devesh Anavkar.

Front cover artwork: Aiden Lim (Year 11)

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.

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 is currently working in private practice as a Consultant Neurologist at Memorial Hospital. Rob was President of the PAOC 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, Nick now works through his private company, Kintan Pty Ltd, in the fields of venture capital and consulting. Nick is an advisor to Sydney based venture capital company, Innovation Capital, and is an associate of Quaero Investment Solutions. He is involved in a number of high technology start-up companies.

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 holds 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 has been 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 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

Richard graduated from ANU in Science with Honours in Pure Mathematics and majors in Applied Mathematics and Computer Science. In 1989, he joined the Bankers Trust in the funds Management Department. Richard moved to Salomon Smith Barney in 1996 and was Co Head of the Equity Capital Markets. After 12 years in finance in Sydney, he moved to Brisbane. Since 2001, he has been the Chief Executive Officer of Dark Blue Sea, an internet company specialising in domain names.

Andrew Moore, 1984

Andrew completed a B.Sc. and B.Ec. at ANU in Canberra. He went on to pursue a career in business and banking working in Sydney for 6 years with Price Waterhouse Coopers and Bankers Trust (gaining professional qualifications in Chartered Accounting and Finance & Investment). In 1997, Andrew spent a year in France doing an MBA at INSEAD. He then joined General Electric in London as a Business Development executive, working on corporate acquisitions for GE throughout Europe. In 2004, Andrew returned to Australia with GE as Managing Director of their Home Lending business in Australia and NZ. In 2008, Andrew joined St.George Bank as General Manager of Retail Banking. He went on to hold a series of senior executive roles within St.George and the Westpac Group until 2016. In 2017 Andrew joined the fintech business Spaceship, initially as Chairman and more recently as CEO. Spaceship is focused on enabling young working Australians to invest in their future by providing them with simple, engaging, low-cost investment and superannuation products, all supported by a highly scaleable technology platform.

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 a M.Sc. in Laser Physics at ANU in 1995 and undertook a Masters degree in Theology at the Melbourne College of Divinity. He is now the Moderator-elect of the Uniting Church Synod of Victoria and Tasmania and will be taking up the role of Moderator at the Synod meeting in mid 2022. In the meantime, David continues to be the Minister of High Street Uniting Church, Frankston.

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 best Physics student. Mitchell completed missionary work for his church in 2003 and then undertook an M.B.,B.S. at Flinders University. In 2008, he was an intern at the Lyell-McEwin 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

Joshua graduated from the SACE in 2020 and after contributing to the Science Journal for several years whilst at Princes he became the Chief Editor in his final year of Senior schooling. On graduating from Princes he studied Marine Biology at the University of Adelaide and was excited for what future scientific endeavours he will encounter.

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.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2024 ROYAL ADELAIDE SHOW - FIRST PRIZE
SCIENCE INVESTIGATION AWARDS YEAR 7

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Eighty years of innovation in molecular biology

Words by Dr James Miller

Guest article

Even from a young age, I had a strong interest in technology and how things work. In high school I had a particular interest in computer programming and loved learning about science. However, what set my future career path was when I studied DNA and inheritance at high school. I immediately knew I wanted to work in this field.

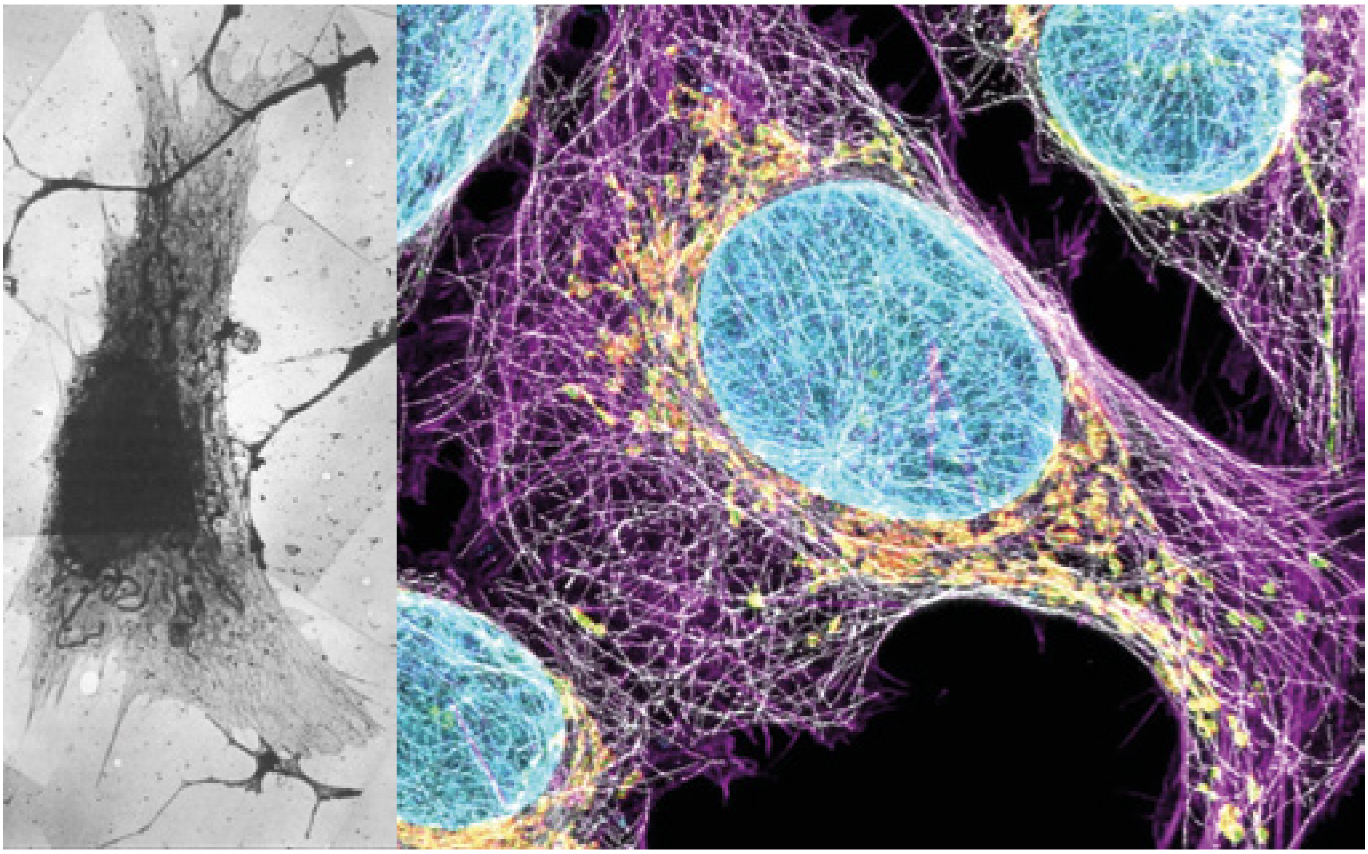
After spending many years at university, followed by working in applied plant biotechnology, I finally landed in the commercial world of selling cutting-edge new technologies to scientists. This journey has really made me reflect on how technology has been instrumental in enabling scientific discoveries so I thought it fitting that for this 80th edition of the science journal I could reflect on key technological innovations over this time, many of which I have had the pleasure of introducing to scientists in Australia in my commercial roles where I have represented many of the companies that produce the latest cutting-edge equipment and methods.

Over the past eight decades, technological innovations have profoundly transformed the landscape of biological science, driving unprecedented discoveries and expanding our understanding of life at the most intricate levels. From the advent of molecular biology to the rise of genomics and synthetic biology, technology has been the engine behind many of the field's most significant breakthroughs.

The emergence of molecular biology

The journey of technological advancement in biological sciences began with the development of molecular biology in the mid-20th century. Central to this revolution was the invention of the electron microscope in the 1930s. Unlike traditional light microscopes, electron microscopes use electron beams to achieve resolutions far surpassing optical limits. Ernst Ruska, a German electrical engineer, is credited with inventing the electron microscope in the 1930s. However, it was not until 1945 that the first electron micrograph of an intact cell was published.

This technological leap allowed scientists to visualize cellular structures in unprecedented detail, laying the groundwork for understanding the complexity of cellular machinery.



The first electron microscope image of a cell (left) and a cell imaged with modern fluorescence microscopy methods (right).

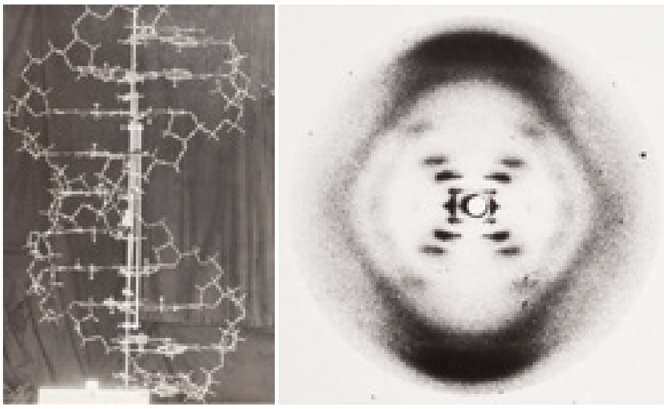
Electron microscopes can resolve structures down to less than 1 nanometer, allowing scientists to visualise sub-cellular components such as organelles—like mitochondria, endoplasmic reticulum, and Golgi apparatus—as well as complex macromolecules including proteins and nucleic acids. This capacity to see inside individual cells led to significant discoveries regarding the organisation and function of these organelles, enhancing our understanding of their roles in cellular processes. Detailed imaging enabled researchers to investigate important structures such as the nucleus, cellular membranes, and cytoskeletal elements, revealing how these components contribute to overall cell function and dynamics.

More recently, the development of confocal microscopy in the 1980s allowed scientists to capture high-resolution, three-dimensional images of biological specimens. This technique, coupled with fluorescent markers, enabled the visualization of dynamic processes within living cells, such as protein interactions and cellular signaling.

Today, super-resolution microscopy techniques, such as STED (stimulated emission depletion) and PALM (photoactivated localization microscopy), have pushed the boundaries of spatial resolution beyond the diffraction limit of light. These techniques have provided insights into cellular structures at the nanometer scale, revealing the intricate details of molecular complexes and cellular organelles.

Discovery of the double helix and the DNA code

The 1950s and 1960s marked another pivotal moment with the discovery of the DNA double helix structure by James Watson and Francis Crick. This breakthrough was made possible by X-ray crystallography. The ability to visualize the three-dimensional structure of DNA heralded the beginning of molecular genetics, leading to the sequencing of genes and the exploration of genetic code.



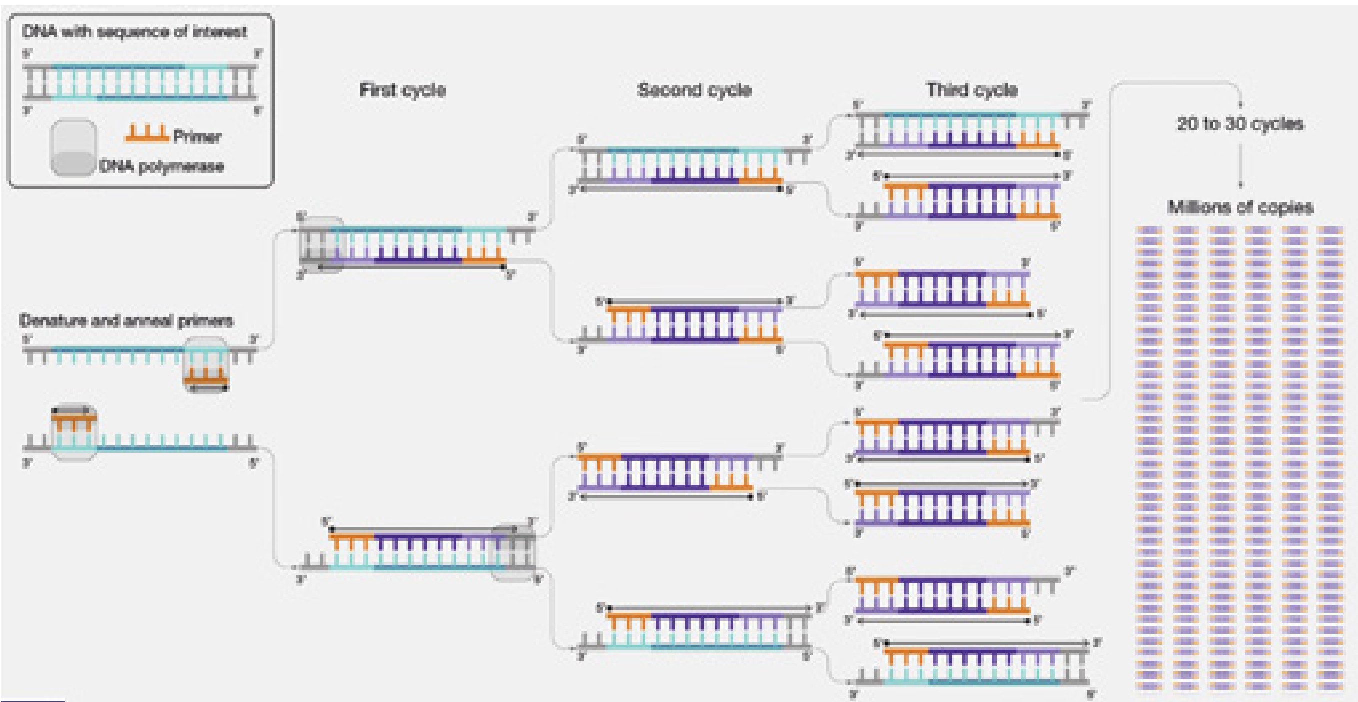
Watson and Crick's discovery of the double helix structure of DNA. Model of DNA structure (left) that was inferred from X-ray crystallography images (right).

However, it was not until the invention of Sanger DNA sequencing in the late 1970s that our understanding of genetic information and how life functions at a molecular level was revolutionised. Developed by Frederick Sanger and his team, this method allowed scientists to accurately determine the order of nucleotides in DNA sequences, which is fundamental to understanding genes and their functions.

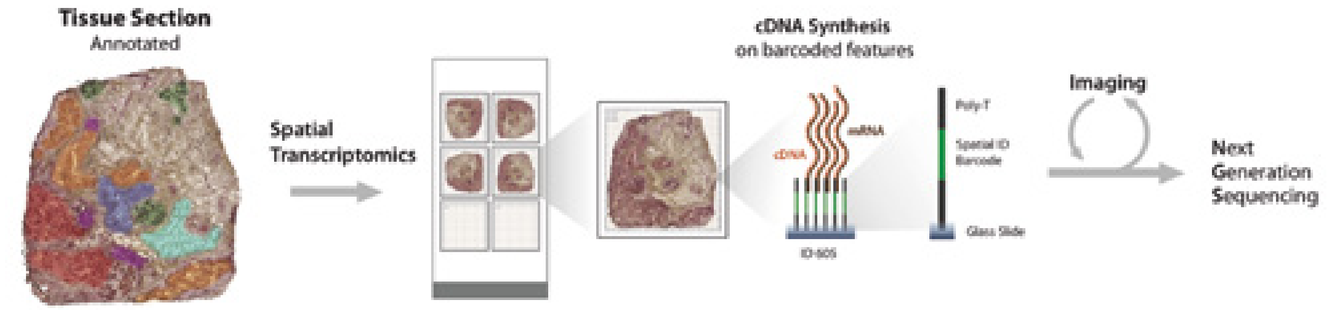
Consequently, Sanger sequencing became a foundational tool, fundamentally altering our conception of life and its biological complexities. Additionally, Sanger sequencing laid the groundwork for large-scale genomic projects, including the Human Genome Project, and this method of DNA sequencing is a still significant part of the DNA sequencing market today.

Polymerase Chain reaction (PCR)

The 1980s introduced another transformative technology: the polymerase chain reaction (PCR), invented by Kary Mullis. PCR enabled the amplification of specific DNA sequences, making it possible to study genes with unprecedented



The Polymerase Chain Reaction (PCR).



Spatial transcriptomics method of gene expression analysis.

precision and efficiency. This technique revolutionized genetic research by allowing scientists to replicate small quantities of DNA into large amounts, facilitating genetic analysis, cloning, and sequencing. PCR became indispensable for a range of applications, from genetic fingerprinting and diagnostics to evolutionary studies and forensic science.

PCR is now a cornerstone of nearly every molecular biology assay. PCR has been widely used in important applications such as measuring the activity of genes, detecting the presence of pathogens - crucial in disease outbreak responses, and to analyse DNA from crime scenes in forensic investigations. Overall, PCR opened new avenues for research and clinical applications and enabled advancements that have transformed our understanding of genetics and molecular biology.

Gene expression

A genome is the complete set of genetic material in an organism, consisting of DNA that encodes all its hereditary information. Proteins are produced through a two-step process: transcription and translation. During transcription, specific DNA segments are copied into messenger RNA (mRNA) or transcripts. This mRNA transcript then travels to the ribosomes, where translation occurs, converting the mRNA sequence into a chain of amino acids, forming a protein. Transcriptomics and proteomics are the fields of study of the entire set of transcripts and proteins in an organism respectively.

We commonly want to measure the transcriptome because it gives us information about how active genes are. These techniques are collectively known as gene expression analysis. Gene expression analysis has evolved significantly over the years, transitioning from PCR methods (e.g. quantitative PCR or qPCR) to high density microarrays and then to next-generation sequencing (NGS), with each stage offering increasingly comprehensive data and insights.

Initially, qPCR allowed researchers to quantify transcripts from single genes in a targeted manner, providing robust data on the expression levels of individual genes. However, its limitation lay in analysing only a handful of genes simultaneously, restricting broader biological insights.

Microarrays, first invented in the mid-1990s, revolutionized this field by enabling the simultaneous gene expression analysis of thousands of genes. This method uses thousands of small synthetic pieces of DNA (known as probes) to capture and measure the transcripts from a sample. Thousands of these probes are printed on small glass slides and RNA samples are applied to the slides where the probes capture them. The number of captured transcripts for every probe is then measured using high power imaging methods. This technology allowed for the profiling of gene expression patterns of thousands of genes across different conditions or treatments, uncovering biological pathways and networks with greater depth. However, this required knowledge of the sequences of the genes to be analysed to make the probes.

By the mid-2000s, NGS had gained prominence and further transformed gene expression analysis. NGS facilitates massively parallel sequencing of gene transcripts without prior knowledge of the genes to be analysed. The NGS DNA sequencing systems have revolutionised molecular biology by providing millions of sequences in a matter of days and this is why they are referred to as high throughput. NGS not only allows for high throughput quantification of gene expression levels but also captures different forms of the expressed genes such as alternative splicing events. This approach provides unparalleled insights into the complexity of the transcriptome and is still used today by many researchers.

Traditionally, genomic studies have been conducted by extracting RNA in bulk from populations of cells, which can mask important variations of gene expression at the single-cell level. By about 2010, researchers started working on technologies to analyze the gene expression of individual cells with the aim of uncovering cellular heterogeneity within populations and revealing distinct cell states and functions that average bulk analyses would miss. The methods that were developed enabled researchers to amplify and sequence the tiny amounts of RNA in an individual cell and apply NGS to sequence them. This also required increases in NGS sequencing capacity. By 2020, single cell gene expression technologies had increased dramatically in complexity and throughput and had opened a whole new field where 1000s of cells could be prepared in a few hours and sequenced and analysed in a matter of days.

Together, these single cell gene expression analysis innovations have drastically enhanced our understanding of gene regulation and cellular dynamics in health and disease. They have been particularly valuable in studying complex tissues, such as tumors, where understanding the diversity of cell types and their interactions is crucial for developing targeted therapies. Today, the field is moving towards cutting edge techniques to not only perform transcriptomics on thousands of cells but also preserve their spatial context to allow researchers to map where specific genes are expressed within the tissue architecture. Several technologies have been invented and are only just now commercially available to enable this work.

The human genome and NGS

The Human Genome Project, initiated in 1990 and completed in 2003, ushered in the genomics era. Driven by the development of the NGS technologies described above, the project was a monumental undertaking that mapped the entire human genome.

The human genome project started by using sanger sequencing to decode the DNA sequence. However, this involved sequencing one molecule at a time - an arduous task for a genome of 3 billion bases. Ten years into the project, in the year 2000, NGS was invented and provided the capability to sequence millions of sequences in parallel at the same time, but it came at a cost. The difference was that NGS sequenced short sequences of only 100 to 200 bases at time, compared to sanger sequencing that could sequence DNA of up to about a thousand bases. However, the huge increase in throughput allowed the project to be completed, even though the bioinformatic "puzzle" of assembling all the sequences was significantly harder. Luckily, the data produced from the sanger sequencing was enough to help complete the puzzle and the two types of data were combined to complete the genome. The analogy is that it is much easier to put together a 100-piece jigsaw compared to a 1000-piece jigsaw.

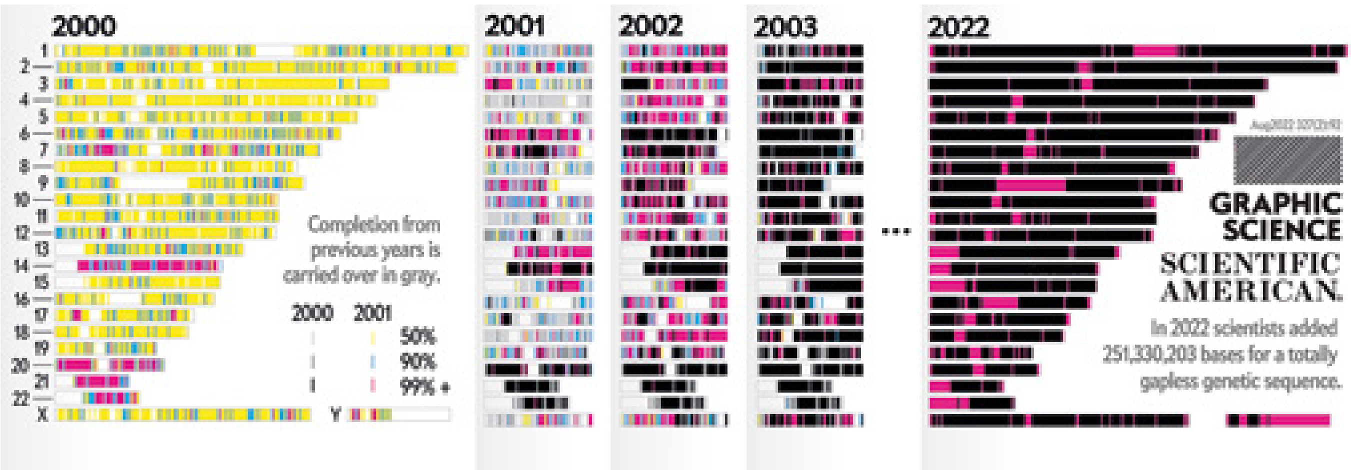
Once the first human genome was assembled, we now had a reference. The concept of a reference is extremely important because now we can sequence different people's genomes, and we don't need to assemble them. We just align all the sequence to the reference and look at where the differences are. This is what is done, even today, when NGS is used in whole genome sequencing (WGS) to sequence a person's genome. The completion of the human genome sequence and WGS opened new avenues for personalized medicine, revealing genetic predispositions to diseases and enabling the development of targeted therapies.

But there is a problem with WGS that is actually a scandal. And this is that WGS is not "whole" genome sequencing and does not resolve or even sequence the whole human genome, and the human genome was never completed and finished in that original project. Nearly 10% of the human genome was intractable to NGS and sanger technologies and was never assembled, the reason being that much of the genome has sequences that are very similar to each other or are highly repetitive or low complexity and just don't get sequenced or are unable to be correctly interpreted. Many of the sequences are impossible to assemble or compare when you have short pieces of DNA sequence. And can you guess how we address that with human WGS? The answer is scientists ignore it. And we pretend those parts of the genome don't exist, even though we know there are many medically relevant genes in some of those parts of the genome.

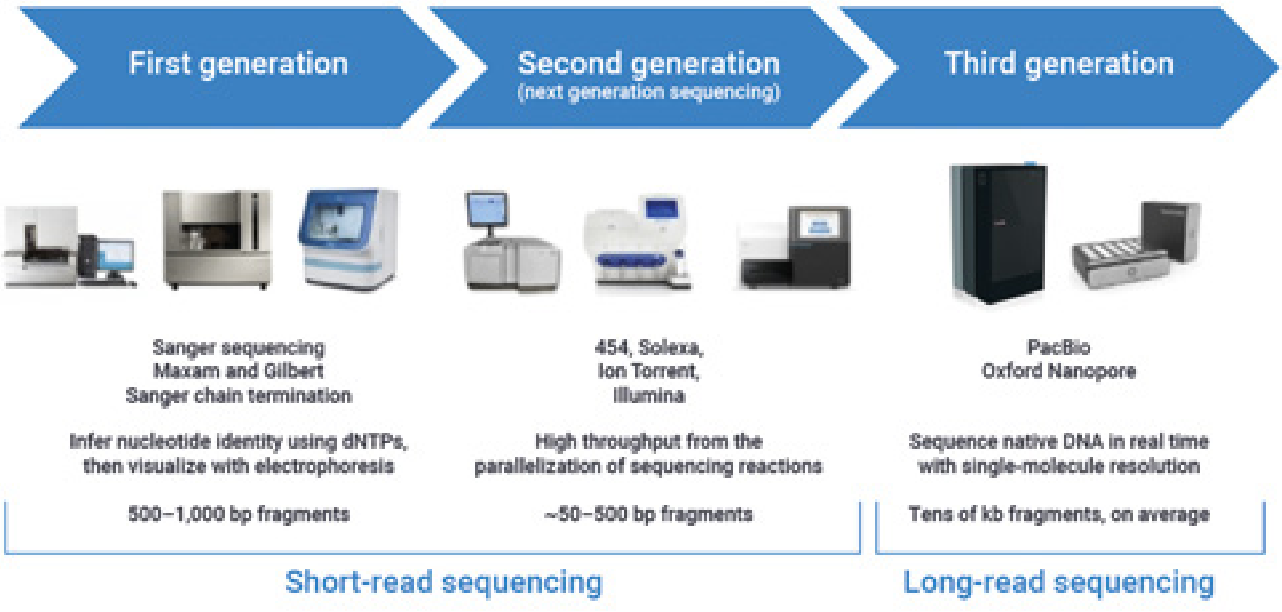
It is only in the last few years that recent advances in DNA sequencing technologies have made it possible to see the missing parts of the human genome. These new innovations are termed long-read sequencing. Long-read sequencing provides sequences that can span tens of thousands of bases, effectively being able to resolve long repetitive or low complexity regions and enabling a more comprehensive view of the genome architecture and the variation that exists within it, including very large changes such as complete additions and deletions of regions that span 100s to 1000s of bases pairs. This capability gives researchers insights into genomic contexts that short reads often miss, enabling a more complete and accurate representation of genomes.

Furthermore, long-read sequencing has made it possible to assemble genomes much more easily and resolve the missing regions from the original human genome project. Again, the analogy is that it is much easier to put together a 10-piece jigsaw puzzle than a 5000-piece jigsaw puzzle correctly, especially when there is lots of sky! It was only last year that the true complete human genome was published, and it is now possible to do this within a few days for only a few thousand dollars using these new technologies. It is widely believed that sequencing technologies, aided by long read sequencing, have advanced to the point where we can resolve every genome completely and accurately.

This shift from short-read to long-read sequencing has been particularly revolutionary in the context of clinical diagnostics. For instance, conditions linked to large deletions, duplications, or translocations can now be better characterized thanks to the longer reads that can traverse these complex regions. As a result, previously unresolved genetic disease cases are now being solved. These advances are still not widely available in



The history of the human genome assembly over the last 22 years. Most of the activity happened during 2000–2003 and 2022, with relatively minor changes in the intervening years. Colors of each region indicate that the region reached 50, 90 or 99%+ completion in that year.



The advancement of commercial DNA sequencing technologies.

clinical diagnostics and are only now being tested in a small number of locations around the world that employ the latest methods.

The rise of omics, big data and machine learning

The word "omics" refers to a field of study in biological sciences that ends with -omics, such as genomics, transcriptomics, proteomics, or metabolomics. There is currently a trend in biological science to generate all these types of data from biological samples and integrate them together to make discoveries and gain insights in biology. However, the sheer volume of data generated by modern biological experiments can be overwhelming to analyse. Machine learning and artificial intelligence offer promising solutions to these challenges. These technologies can process vast amounts of biological data, identify patterns, and make predictions with high accuracy.

AI algorithms, particularly deep learning models, will likely enhance our ability to identify complex patterns and correlations within vast datasets, leading to more accurate predictions of disease susceptibility, drug responses, and personalised treatment plans. For instance, AI-driven models could revolutionise cancer research by predicting patient-specific cancer progression and treatment outcomes based on multi-omics profiles. In one example, AI algorithms are already being used to predict protein structures, analyse genetic data, and model complex biological processes. AlphaFold, developed by DeepMind, has made significant strides in predicting protein folding, a critical aspect of understanding protein function and drug design.

This future promises a new era of personalized medicine, where treatments and preventive strategies are increasingly informed by rich, multi-dimensional biological insights.

Conclusion

Technological innovations over the past 80 years have been instrumental in shaping the field of biological sciences. From the early days of molecular biology to the modern era of genomics, bioinformatics, and synthetic biology, each advancement has propelled our understanding of life and opened new avenues for exploration and application. As technology continues to evolve, it will undoubtedly drive further discoveries, offering new insights into the mysteries of biology and advancing our ability to address some of the most pressing challenges facing humanity. This ongoing relationship between technology and science has been a source of inspiration throughout my career, continually reaffirming my passion for the field and driving my commitment to advancing scientific discovery.

1940s

Richard James invents the slinky spring

How have NAD+ supplements impacted society's quest for eternal youth?

Words by Aryan Parwal (Year 11)

Thought starters

Australia's population is aging, with approximately 1 in 6 Australians being 65 or older as of 2020, and this percentage is projected to increase. The risk of age-related diseases increases with age. The belief in the potential benefits of anti-aging supplements to delay the onset of these illnesses and provide anti-aging benefits has fuelled their popularity in the past decade. Nicotinamide Adenine Dinucleotide (NAD) is one such supplement believed to mitigate the negative effects of aging, such as the development of chronic diseases and the aging process itself. NAD^+ is a coenzyme essential for cellular energy production and repair in all human cells. This report will focus on the influence NAD+ supplements have on the medical, pharmaceutical, and anti-aging industries.

NAD^+ is a coenzyme that is crucial for carrying out chemical reactions within the body. Coenzymes are small molecules that aid enzymes in catalysing various reactions. Additionally, enzymes are proteins that catalyse biochemical reactions by reducing the activation energy required for reactions. This is achieved by inducing strain and distortion on the substrate bonds, making certain bonds weaker and more susceptible to breaking. This provides an alternate metabolic pathway for the reactants to turn into products. There are specific areas on the enzymes called active sites that bind to a particular substrate. The induced-fit model explains how the active site adjusts its shape to precisely fit the substrate, forming the foundation of enzymatic activity. NAD is the general name used to describe Nicotinamide Adenine Dinucleotide. NAD^+ refers to the active biological form of NAD with catalytic abilities. NAD, after receiving electrons and a hydrogen ion, transforms into NADH.

Aerobic respiration is a chemical process carried out by many living cells to produce cellular energy. During respiration, glucose is first broken down in the cytoplasm to form pyruvate. The next phase, the Krebs Cycle, is composed of many stages of biochemical reactions that are intended to release stored chemical energy in nutrients, so the energy released, forms ATP (adenosine triphosphate). The cycle starts with Acetyl coenzyme A (a two-carbon-molecule) which reacts with oxaloacetate (a four-molecule-carbon) to form citrate (a six-carbon-molecule). The citrate is further transformed into isocitrate, which is an isomer of citrate. After the synthesis of -Ketoglutarate, but before the synthesis of isocitrate, one molecule of carbon dioxide is produced and one molecule of NAD+ is then converted into reduced NADH.

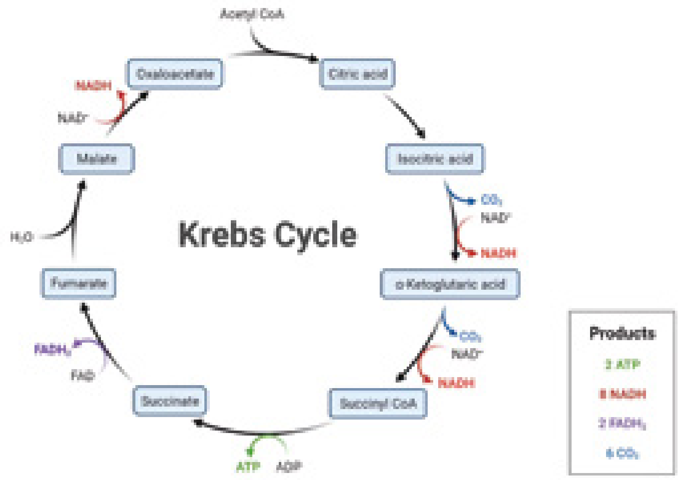


Figure 1: This figure illustrates the process of the Krebs Cycle, detailing the reactants and products generated at each stage.

Two additional NADH molecules are produced throughout one round of the Krebs Cycle, and one molecule of oxidised flavin adenine dinucleotide (FADH2) is derived from flavin adenine dinucleotide (FAD). Additionally, one molecule of ATP is generated through substrate-level phosphorylation. The Krebs Cycle repeats twice, and so the end products after two repeats consist of two ATP molecules, four carbon dioxide, six NADH molecules, and two FADH2 molecules. See Figure 1 below:

Apart from aiding the production of ATP, NAD+ supplements also aid in other cellular processes such as DNA repair by decreasing the accumulation of endogenous DNA damage which improves DNA's repair capacity.

NAD+ supplements have influenced the scientific and medical fields due to recent theories about regulating life processes in organisms. Shinya Yamanaka demonstrated the feasibility of cell reprogramming through extensive experiments in mice, showing that it could enhance health and resilience in human cells. Throughout history, countless people have attempted to halt the aging process. Yet, scientists have long grappled with uncovering the underlying factors that contribute to the process of aging. From 1558, when women first discovered the wrinkle-reducing properties of meat applied to the face, to the early twenty-first century, when creams and pills became readily available in pharmacies, humanity has incessantly pursued to look more cosmetically appealing.

NAD was first discovered in 1906, but it became more widely known in the early 21st century, especially after the discovery of sirtuins in 2000. Sirtuins are proteins that depend on NAD+. The concept of "NAD World" emerged, suggesting sirtuin 1 as a key regulator of aging and longevity in mammals. This sparked increased interest in the coenzyme NAD+ and led to a revolution in the anti-aging industry.

As organisms age, their tissue and cellular NAD+ levels gradually decrease, impacting various model organisms like

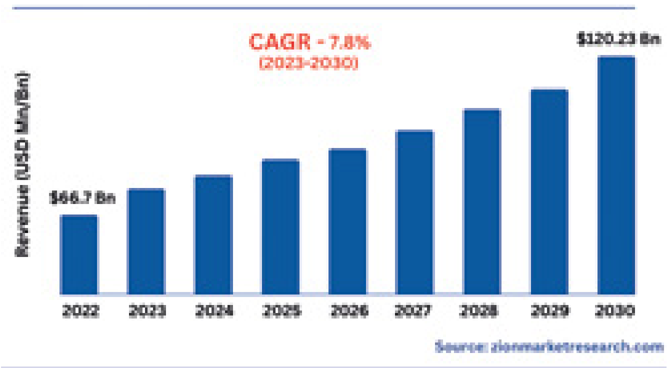


Figure 2: The global anti-aging industry is projected to experience rapid growth until 2030.

rodents and humans. Numerous age-related illnesses, such as sarcopenia, cognitive decline, and frailty, are directly linked to this drop in NAD+ levels. Many of these illnesses may be slowed down or even completely cured by raising NAD+ levels. Thus, focusing on NAD+ metabolism has become a viable treatment strategy to reduce age-related illnesses and increase human lifespan and overall health.

Moreover, the popularity of anti-aging supplements, including NAD+ supplements, is increasing as many people strive to look and feel younger. This trend has significantly influenced both the pharmaceutical and cosmetic industries and the anti-aging sector. NAD+ supplements can delay the onset of age-related diseases such as cancer and metabolic diseases, thereby reducing biological age and reversing age-related immune system decline.

As NAD+ plays a pivotal role in numerous metabolic processes, NAD+ supplements have emerged as agents for rejuvenating aging cells, targeting pivotal mechanisms like damaged DNA and inefficient mitochondria. As a result, it has influenced the research into NAD+ boosters, with trials underway to seek FDA approval for drugs aimed at combating aging. Moreover, these trials have spurred and influenced the development of other scientifically supported anti-aging medications, like recent trials involving metformin, originally a diabetes treatment. Successful outcomes from these trials could incentivise major pharmaceutical firms to invest more resources into anti-aging research, particularly into NAD+ supplements. Consequently, the emergence of NAD+ boosters has influenced not only the pharmaceutical industry, but also legislation in both the pharmaceutical and anti-aging sectors.

The utilization of anti-aging products such as NAD+ supplements within the scientific community has significantly reshaped public perceptions that were once steeped in negativity towards anti-aging interventions. Historically, the anti-aging industry bore a heavy stigma, partly due to marketing tactics employed by cosmetic companies. Additionally, these products are merely showcased through societal influences propagated by the media, promoting the idea of maintaining a "youthful look", which undermines the concept of embracing the "natural aging" process gracefully. However, with the increasing prevalence of NAD+ supplements and their "scientific backing", the industry and public perception of anti-aging is shifting from gimmicky products to promoting lifelong health by preventing diseases typically associated with aging. This evolving perspective may pave the way for more scientifically substantiated anti-aging products to enter the market, providing consumers with more informed choices.

Finally, products like NAD+ supplements have significantly boosted the economic development of the anti-aging industry, enabling a steady growth rate of 7.8% annually (see Figure 2).

Currently valued at approximately sixty-six billion USD, the anti-aging industry is predicted to reach one hundred and twenty billion USD by 2030, clearly indicating that this industry will yield substantial economic benefits in the future. Furthermore, consumers recognize the importance of maintaining their health and preventing diseases before they arise, leading to increased spending on anti-aging supplements.

These products signify a recent breakthrough and stand out for their uniqueness. Consumers trust the scientific validation behind them, which attracts more buyers and establishes a new niche in the anti-aging market. This also contributes to the expanding 'natural products' segment.

In addition to their anti-aging properties, NAD+ supplements can enhance energy levels and endurance by aiding mitochondria to produce NADH, the cell organelle responsible for ATP synthesis. By ramping up cellular metabolism and ATP production, NAD+ supplements can enhance physical performance and alleviate fatigue, making it particularly advantageous for athletes and individuals seeking to enhance muscle function and athletic ability. Additionally, NAD^+ has proven effective in addressing addiction and withdrawal symptoms by bolstering neurotransmitter production associated with addiction and mitigating oxidative stress, thereby curbing cravings, and fostering improved well-being during recovery. Furthermore, NAD+ supplements have been found to bolster immune function by bolstering the production and efficacy of immune cells, consequently improving overall health, and diminishing susceptibility to infections and ailments. This also leads to enhancements of the body's metabolic processes, further contributing to overall well-being. As well as curing certain illnesses and diseases, the future for NAD^+ is looking very promising. While there are many different areas of medicine which NAD^+ may impact, the main area for potential NAD^+ application is the use of NAD^+ in prescription medication, with tailored medication given to patients based on an individual's NAD^+ levels and metabolic profile.

In conclusion, NAD+ supplements have significantly impacted society's quest for eternal youth by providing promising strategies to address age-related illnesses and improve overall well-being. With Australia's aging population growing, there is a rising demand for anti-aging solutions. NAD^+, a crucial coenzyme essential for cellular energy production and repair, has become a symbol of optimism in this endeavour. Scientific progress in understanding NAD^+'s role in cellular processes and aging has spurred the creation of NAD+ supplements, shaping not only the medical and pharmaceutical fields but also altering public perceptions of aging. Further exploration of NAD+ metabolism and its potential for tailored treatments based on individual characteristics foreshadows exciting developments in anti-aging medicine.

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The flavoursome discovery of jellybeans

Words by Ben Logan (Year 7)

Figure 3-Glucojel Jelly Beans

Thought starters

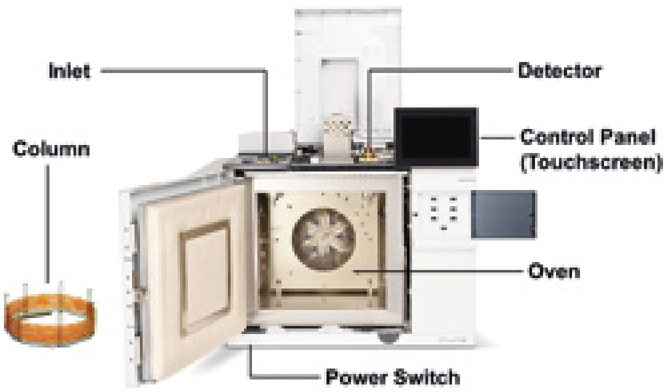

Figure 1- an annotated diagram of a gas chromatograph

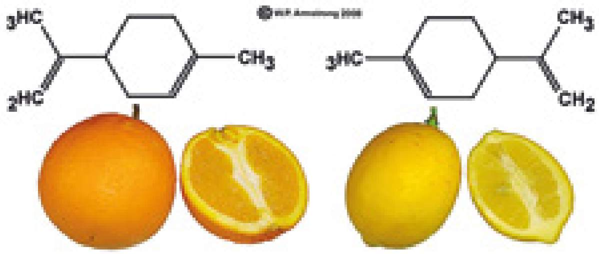

Figure 2- Orange and lemon are mainly constituted from the same molecule, limonene, but different enantiomers: R-limonene and S-limonene.

Some of the most underrated and underestimated scientific discoveries that would barely even cross your mind is the chemistry behind many lollies, such as jellybeans. There is so much more background to these lollies than one might think, yet not many people would care about how they are made, only how they taste.

A brief history, these lollies were originally made by the Goelitz confectionary company in the 1960's. However, they were only brought to life in 1976 when David Klein worked with Goelitz to create Jelly Belly. Since then, these lollies have grown significantly, now ranging in many flavours, and are icons of many people's childhoods.

From sweet lemon to disgusting fish, all these unique and wonderful flavours have a lot more background than just the sweetness in your mouth. The chemistry of jellybeans is usually goes unnoticed as the taste generally overpowers all other molecules at work.

To create new jellybeans, which is happening probably as you read this, the vapours of the food or drink come into play. Using a gas chromatograph (Figure 1), the scientists analyse the chemical composition of those vapours (Figure 2), and then turn them into flavour markers. This is what factories use as a starting point in creating those flavours. For example, if "mouldy cheese" was a new flavour, a scientist would leave cheese in a warm room for a week, analyse it with the gas chromatograph, and then create the new flavour with the data that is generated.

From the day these favourites took the world by storm in the 1960s, they have been one of the most successful lollies. They have gradually gained global popularity and are now known and loved by people of all ages. Although you may not think it, these lollies can be beneficial in ways that are not just for the taste buds. The Glucojel jellybeans (Figure 3) are specially manufactured to contain high levels of sugar. These have proven vital for diabetics who use them when their sugar levels are too low. Overall, these lollies have had many instrumental impacts on our world to this day and they will keep advancing in the future.

The chemistry behind these and many other lollies is very interesting and, if we are thinking in the long, long term when we might be living on Mars, could provide us with bite-sized meals that taste just like the ones back here. So, the possibilities are endless with these lollies and just how much of an impact the basics of these flavours could have is astonishing.

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Peto’s Paradox

Words by Charles Li (Year 10)

Thought starters

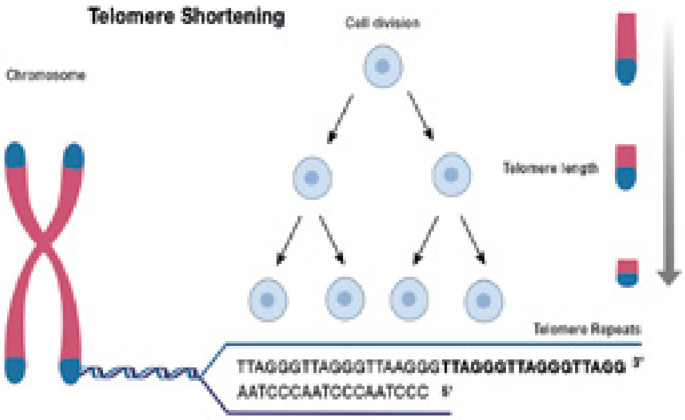

Figure 1 - Telomeres

Cancer, something so fierce that attacks the very foundation of life itself makes it seem like an unsurpassable filter which kills indiscriminately. Much progress has been made over the last 80 years in the detection and treatment of various forms of cancer. However, in the process of discovery and experimentation of trying to find a cure for cancer, in 1977, something potentially revolutionary yet unexplainable appeared. Large animals seem to be immune to cancer. This was coined ‘Peto’s paradox’ and it is the exact opposite of what we expect. To understand why Peto’s paradox is so puzzling and understand the theoretical possibilities behind it, we first need to understand the principles of cancer and how it even came to existence.

A somatic cell reproduces through a process known as mitosis, where it copies its own DNA then aligns them into chromosomes before attaching them to two opposite ends of the cell to be split into two almost identical daughter cells. This process, however, is not perfect. Every time the DNA is replicated, it has a chance to miscopy base pairs, resulting in mutations. Fortunately, our cells are extremely specialised and prepared for this, which allows most mistakes to be corrected through processes known as ‘proof reading’ and ‘mismatch repair’. Another feature our cells have developed are telomeres (as shown in Figure 1), situated at the ends of each chromosome. They are essential due to allowing cells to divide without losing any genes. Without telomeres, chromosome ends could fuse together and corrupt the cell’s genetic blueprint, possibly causing malfunction, cancer, or cell death. Telomeres slowly decay over time (Figure 1), which is one of the reasons that cancer risks are strongly correlated with age. Our immune system also has a wide variety of built in mechanisms to limit or exterminate cancerous cells before they multiply, further lessening the odds of them emerging. On top of all of that, most mutations are relatively harmless, only resulting in pseudogenes, and the sign of negative mutation would activate the cell’s ‘kill switch’ to ensure it wouldn’t be a problem (apoptosis). However, with trillions of cells over many years, it’s always only a matter of time before one cell escapes the numerous checks, mutating enough in specific ways (especially proto-oncogenes, (see Figure 2) to develop into a cancerous cell. For example, one mutation could disable the ‘kill switch’, another could make it appear normal to the immune system. This is a problem that is inheritably in every cell, meaning that it affects every organism, and with the increase in size indicating an increase in the number of cells due to all organisms having roughly the same cell size (figure 3), larger animals should have much larger risks of cancer, right?

Wrong. This is Peto’s Paradox, the astonishing discovery of the lack of correlation between body size and cancer risk in different organisms.

Mice have approximately 2% of the lifespan of a human, with only less than 0.05% of our cells, yet they have approximately the same rate of cancer as us. At the other end of the spectrum, blue whales with significantly longer life spans and an average of 3000 times the cells a human has (as shown in figure 4), seemingly never develop cancer. There are currently two main hypotheses for this paradox, evolution and Hypertumors.

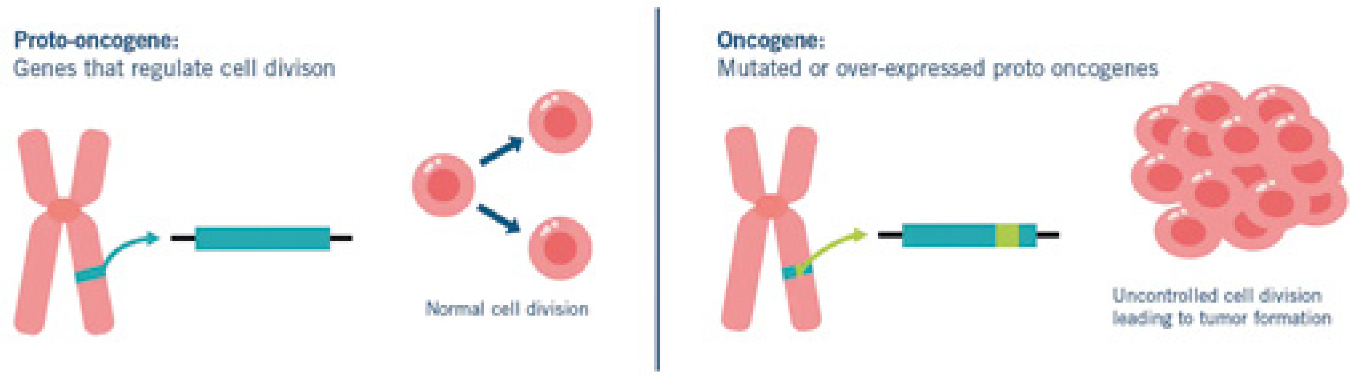

Figure 2 - Proto-oncogenes and how they are important

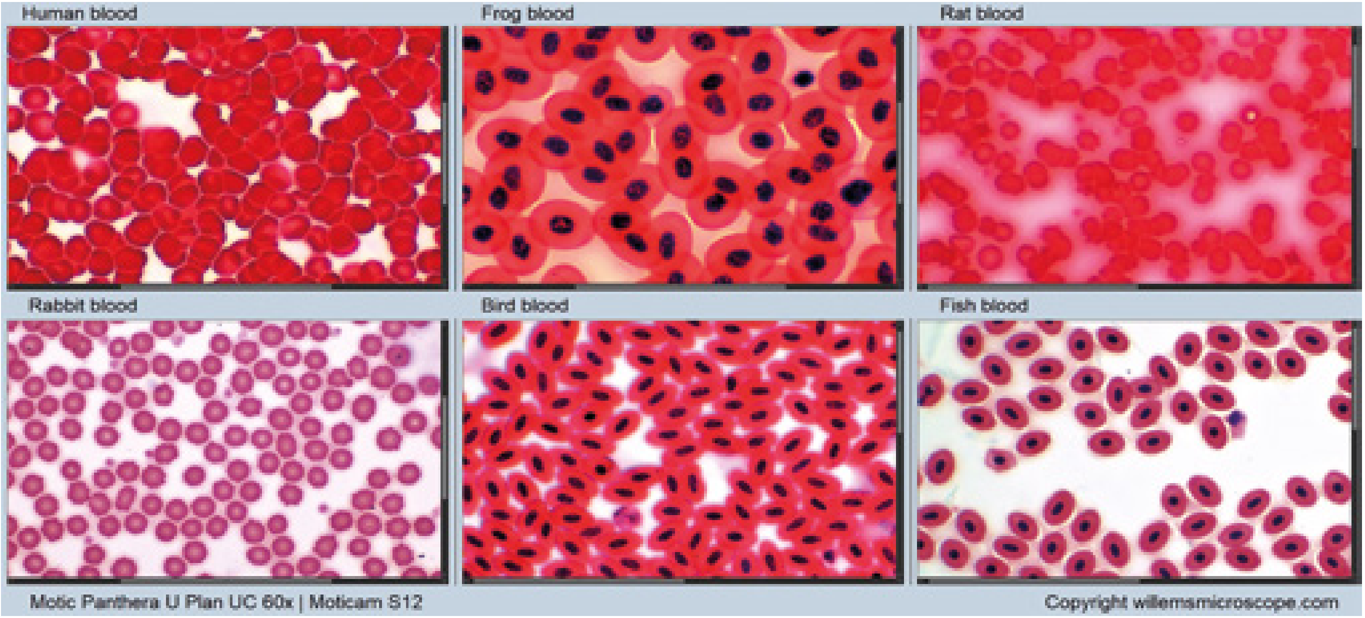

Figure 3 - Comparison of red blood cells in different animals

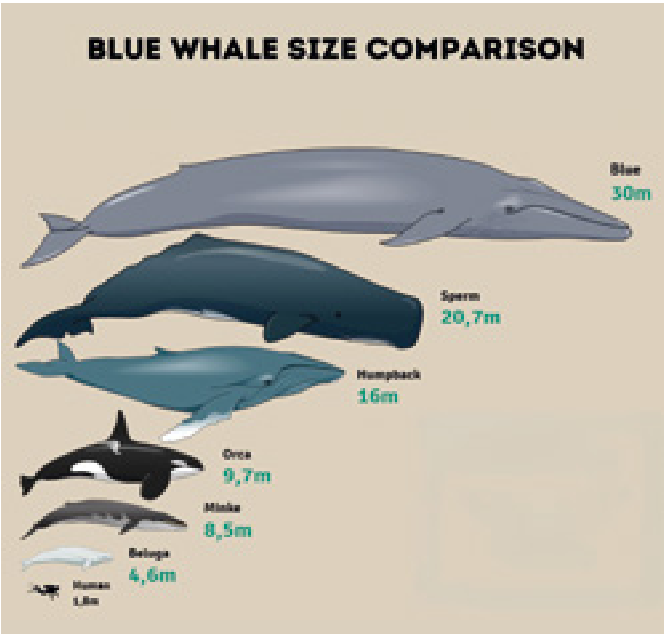

Figure 4 - Size comparison between a blue whale and the average human

Evolution

Due to cancer being a problem with cells itself, it would've been an increasing problem since 600 million years ago as multicellular organisms began emerging. As they increased in size and were composed of increasing numbers of cells, it also meant that their rate of cancer would also increase accodingly. Due to this, organisms were forced to evolve bette traits to combat cancer. Thankfully, evolution found a key to combat this problem, tumor suppressor genes. They are gene which form an internal defence against mutations, helping to fix critical errors or order the suicide of the cell to prevent it from duplicating. Large animals have increased numbers of these genes, such as the TP53 gene (shown in figure 5), that is closely associated with an increased apoptotic response. Due to these genes, large animal cells such as elephant cells woulc require a much larger number of mutations to corrupt them than a human or mouse cell, making them much more resilier rather than immune. This evolutionary adaption would've also been attained at a cost, but it is currently unsure what traits were sacrificed for it. Whilst some theories exist, including it might make them age quicker in later stages of life, or perhaps reduce the rate of recovery from injuries, it is still currently uncertain.

Hypertumors

Named after hyperparasites, the parasites of parasites, Hypertumors the tumors of tumors. Cancer can be viewed as a rebellious and selfish overthrow and refusal of the collaboration between cells, working only for their individual short-term benefit. If a cancer cell is successful, it forms tumors, a collection of cancerous cells which are extremely hard to kill. However, making a tumor is extremely difficult, millions to billions of cancer cells rapidly multiplying demands a lot of resources and energy, which is stolen from the body by tricking it to build blood vessels directly to the cancerous growth, making the body essentially kill itself. The nature and principles of cancer cells, however, cause their ultimate demise. They are extremely unstable which allows them to undergo mutation quite quickly and drastically compared to a normal cell. If this process continues, at some point, one of the copies could create another rebellion and refuse to co-operate with the original cancer cells. This new tumor, known as a Hypertumor, now becomes an enemy of the original cancerous tumor, competing for the same nutrients and resources to grow. This will lead to the new Hypertumor prioritising its own

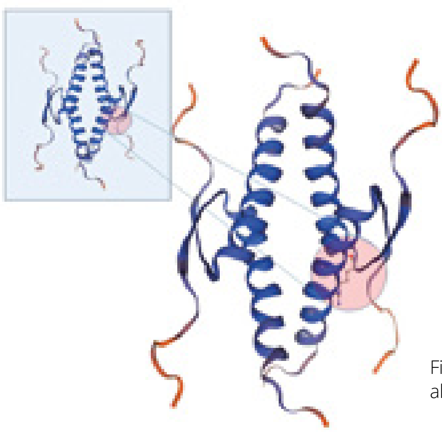

Figure 5 - A TP53 gene alongside a mutated version

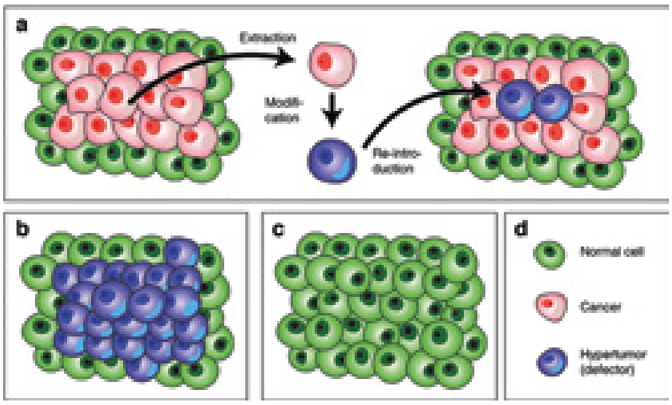

Figure 6 - Theoretical use of Hypertumor knowledge to kill cancer.

growth over its parental cancer tumor, cutting off their supplies in order to feed and grow itself, making cancer kill cancer. This process can repeat over and over, creating Hypertumors that kill the original Hypertumor, and on and on. This process may allow cancer to not be problematic towards bigger organisms, making them have more of these tumors and Hypertumors that we thought, but just not big enough to be noticeable. This does make sense mathematically, a 2 gram tumor is 10% of a mouse's body weight, while it's less than 0.002% of a human's, and 0.000002% of a blue whale's, despite having the same number of tumor cells. So large animals such as the blue whale may have hundreds of tiny tumors, but they just never get big enough to cause a problem.

There are a variety of other solutions to Peto's paradox, such as varied metabolic rates or unique cell structures, but currently they remain unclear. Understanding how large animals overcome cancer is essential to our own journey of conquering it. Perhaps we could harness their genetic traits through CRISPR, or implant Hypertumors in patents to essentially 'reset' cancer tumours to a much earlier and curable state or even modify them to completely kill cancer with no side effects (represented in figure 6). Uncovering this seemingly strange paradox could unlock the gate to a whole new generation of better cancer treatments, a world where in the next 80 years and beyond, cell mutations are only associated with evolution, not disease.

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Subterranean clover: The pasture plant that revolutionised Australian agriculture

Words by Eddie Lock (Year 11)

Figure 1: Subterranean Clover discovered by Amos Howard

Thought starters

For the past 80 years, the agricultural industry has flourished with more innovation and technologies being developed by the decade, improving and benefiting the agricultural industry. However, looking back at the achievements that were made over the past 80 years, one revolutionary plant is overlooked, subterranean clover. Subterranean clover (*Trifollium subterraneum*) is a small seed pasture plant that is used in livestock pastures and is full of the vitamins and nutrients needed to grow out animals such as a lamb or a calf. Additionally, when the plant grows it returns nitrogen back into the soil to benefit other plants around it. This feature as well as the other rich minerals, nutrients, and vitamins that the plant possesses has revolutionised Australian agriculture and will continue to, for many years to come, but how did this all begin?

In 1889, Amos Howard discovered a plant on a roadside near Mount Barker, South Australia as seen in Figure 1. Many of the local farmers believed it was nothing but a 'wayside weed', but Howard saw its potential. The soil in the Blakiston region at the time was low in phosphorus so subterranean clovers (sub clovers) were the only plant that would grow. Howard experimented with the plant and noticed that when phosphorus was added to the clover, the plant flourished growing into a leafy mat with a 2-metre diameter. Howard illustrated the effects to local farmers, and they started to distribute the newly discovered plants. The growing of the clovers in the Mount Barker area was a huge success, increasing the values of farmland, and generating a massive income in seed production, selling the seeds to other parts of Australia and the world. By 1930, the Mount Barker district was receiving 50,000 pounds annually from the clover production and resulted in the first subterranean clover variety being named Mount Barker.

As mentioned earlier, it revolutionised agriculture across Australia, the perfect example of this being in the Kybybolite area, near Naracoorte in the southeast of South Australia. In 1906, the Department of Primary Industries and Regions of South Australia (PIRSA) bought a 1066-acre block to use as an experimental farm for the region as seen in Figure 2. Every style of agriculture was tested to see what would suit the Kybybolite area ranging from cropping to fruit to dairy cattle. Through this it was discovered that the land the farm had been established upon had disappointingly low carrying capacity of about 0.7- 0.8 sheep per acre. With farmers in the region desperately trying to improve their pastures to produce quality sheep, cattle, and other livestock, the scientists began to experiment with pasture plants.

A local farmer who was also a previous manager of the Kybybolite experimental farm, Mr Simeon Schinckel presented a paper to the Naracoorte Branch of the Agricultural Bureau in which he recommended the use of superphosphate for pasture lands. Additionally, after the success of Howard's subterranean clover in Mount Barker and how it benefited from superphosphate, scientists and farmers at Kybybolite decided to implement sub clovers into their pastures to see its effect. Pasture plots were sown, and it was discovered that the sub clover plant was too rich and was not healthy for animals. However, for every one sheep that died on a rich sub clover pasture, twenty died in the need for it, and so research was continued.

Figure 2: PIRSA Kybybolite Experimental Farm

In 1928, the manager of the farm Len Cook reported that a mixed pasture of subterranean clover and Wimmera rye grass that was spread with triple superphosphate annually was far superior to the local natural pasture. Cook reported in 1939 that plots top-dressed with superphosphate averaged 2.41 more sheep per acre than no manure plots. Soil analysis showed that increasing pasture quantity and the number of livestock carried increased the nitrogen content of the soil. Cook concluded that "after twenty years of top dressing the nitrogen content of the soil had been nearly doubled". In the aftermath of World War II, Cook and local farmer Sydney Shepherd tirelessly spread the news of the transformation of 'sub and super'. Syd Shepherd was very rarely at his own farm as he was "away giving advice and helping farmers less fortunate that he was" according to his son Algie.

The success of the pasture revolution in the southeast caught the attention of farmers, scientists, and other agriculturalists around the world. Both national and international markets of subterranean clover seed had begun and by 1961, more than 20 million acres of Southern Australia had been sown with sub clovers. What was once grown in only hundredweights (CWT) or 50kg was now being grown by the tonne. But if the plant was to continue to be grown for seed production at such a huge rate, the technology would have to be made to support this, wouldn't it?

In 1961, the South Australian machinery company Horwood Bagshaw created the vacuum seeds harvester or better known as the 'HB's'. As seen in Figure 3, the harvester was built primarily for subterranean clover, but it was also used for other pasture seeds such as medics. How this machine worked was that it sucks up all the clover burrs, which were pods with the seeds inside and separated the burrs from the rest of the herbage of the plant. After which the thrasher would then rip the burrs from the seed before they could land in the seed box. These machines revolutionized Australian production being able to produce more tonnes of grain than ever before. Bagshaw took inspiration from Ronald Earnshaw since his design was too big and expensive to manufacture for the average farmer. These machines were in production until the early 1990's and farmers made many modifications on them. These harvesters are still being used to harvest sub clovers today, mainly in Kybybolite, Western Australia, and Riverina in NSW.

The HBs were the key to growing the Australian sub clover market into what it is today. The HBs were never exported overseas except for two into South Africa, meaning that Australian farmers had to produce seeds for farmers across the entire world. This gave Australia an advantage in the sub clover department as the production of it has produced millions of dollars for the Australian economy since its discovery.

Over the past 80 years, Mount Barker hasn't been the only variety that has been produced for our pastures. Currently, there are 19 current varieties in use and 18 superseded or retired varieties, all of which have unique characteristics. A number of these being discovered in South Australia as seen in Figure 4: the Seaton Park in 1941 near the Royal Adelaide Golf Club, Clare in 1921 which later commercialized in 1950 in the township of Clare and Mount Barker in 1889 located in Blakiston. Other varieties have been discovered in Western Australia, Victoria, Sardinia, Greece, Turkey, and many have been bred in labs from other varieties.

Although many have been bred to become better versions of current varieties, the natural pastures have managed to last the longest and still continue to produce the best quality crops and seed.

In conclusion, the subterranean clover has revolutionised agriculture around the world, especially in areas where the 'sub and super' formula are still being applied such as the southeast of South Australia. The plants' ability to return nitrogen back into the soil to benefit other plants has revolutionised pastures, producing higher quality livestock for the world. The creation of the HBs not only changed harvesting forever but they also allowed Australian farmers to become world leaders in seed production. The plant has also had a strong influence

Figure 3: HB Clover Harvester in the newspaper

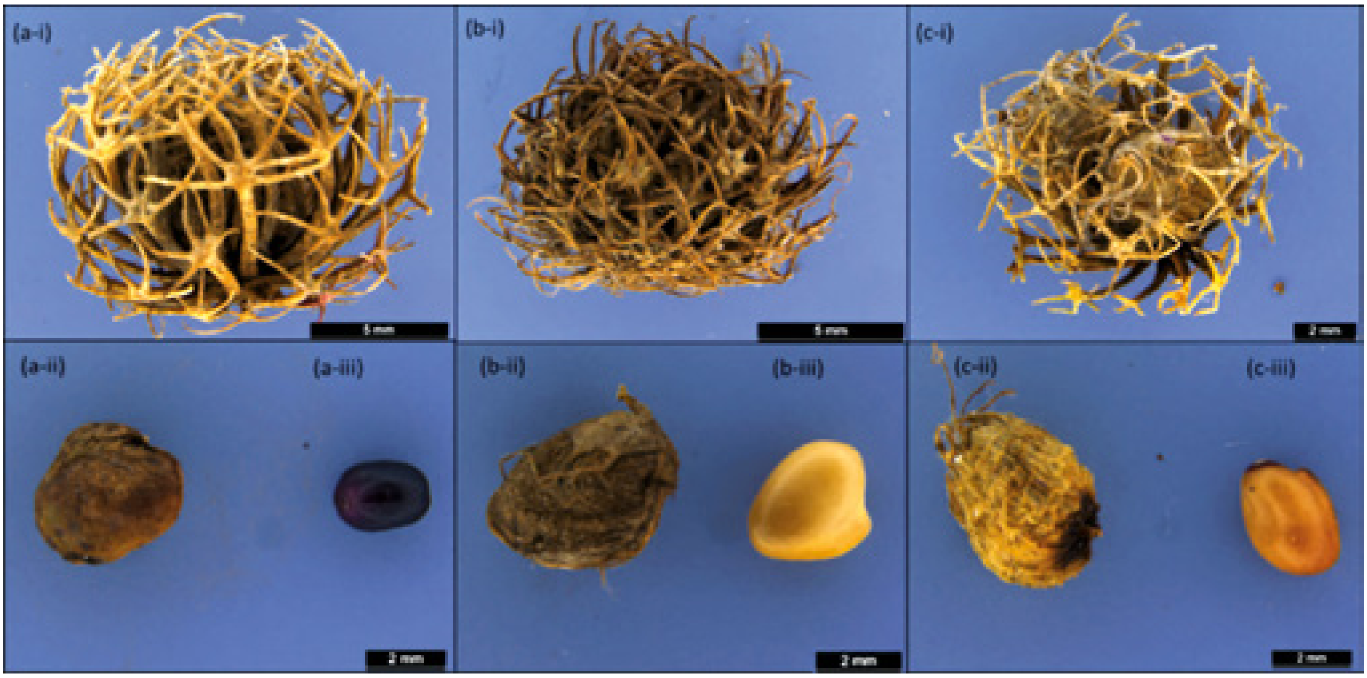

Figure 4: Images of sub clovers: i) burrs containing 3-4 pods, ii) pods containing a singular seeds iii) seeds, a) subterraneum, b) brachycalycinum, c) yanninicum

on agricultural shows in South Australia with the Mount Barker showgrounds and Naracoorte showgrounds' main gates having clover leaves on them in memory of Amos Howard and Sydney Shepherd. These shows also have classes in their grains and fodder sections for sub clover and their seeds which are entered every year and are strongly supported by farmers. If Amos Howard had never discovered this plant, would it still be classified as a 'wayside weed' and what state would our pastures and our soils be in today? The discovery of subterranean clover is an important piece of agricultural history that must not be forgotten as it revolutionised the soil and pastures from which our populations depend on for our food every day.

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The science and history of the LED

Words by Josh Wang (Year 7)

Thought starters

Figure 1: Photo of a LED

Throughout the history of humanity, efficiently emitting light has always been a problem up until the invention of the LED. The LED (Figure 1) is an acronym for "Light Emitting Diode", where a diode is a material that is partially conductive of electricity and only allows the flow of electricity one way.

Without it we would not have the internet, computer/TV screens, and cheap, efficient and bright lighting that every household has. The number of applications for the LED are also wide. Ranging from seven-segment displays, lights on planes, strip lights, glow lights, to OLED displays which are some of the best displays with the best colour accuracy and very low power consumption. The invention of the LED also allowed us to share information at an unprecedented rate through the internet, which led to many more discoveries as scientists were able to share and distribute their findings much easier.

The History of the LED

The concept of generating light by either passing an electrical current or electrical field through a material was first discovered in 1907 by Henry Joseph Round. The first functional LED was made in 1927 by Oleg Losev, a Russian inventor, but the LED was too inefficient for practical use and commercialisation.

For clarification, an LED doesn't have to emit visible light. The LED's made prior to 1962 emitted light that didn't have enough energy to be visible to the human eye. Most LEDs made were infrared diodes that emitted infrared light with longer wavelengths from (1mm to 780nm) and lower energy, compared to visible light that has smaller wavelengths (from 700nm to 300nm) and higher energy.

From 1927-1962, many scientists contributed to the creation of the first visible LED, which eventually was discovered on October 2nd of 1962. This LED was invented by Nick Holonyak, a scientist at General Electric, however it only emitted light in low temperatures and only emitted red light. This was still a huge break through though, and a starting point for what would eventually become a 72-billion-dollar industry.

As time passed, scientists and inventors found new and more efficient ways to produce light through an LED. There was the creation of the green LED by engineers at the Monsanto company in 1972. They also found new ways to apply LEDs to real life scenarios and problems, such as using them on radio indicators and car stereos.

At this moment, the visible red and green LEDs had been created but the blue LED wouldn't be efficient or bright enough for commercial use until 1993. The blue LED was so important to make because it was the final primary colour of LED that had not been invented yet, and once you are able to make all three primary colours in light, you are able to make any colour of light. This would allow for computer, laptop and mobile phone screens to be create. The first blue LED that was bright and efficient was made by Shuji Nakamura. The blue LED was such a massive breakthrough that Shuji Nakamura won the 2006 Millenium Technology Prize and the Nobel Prize in physics in 2014.

It is also important to note that the first blue LED was invented in 1972 in Stanford, but it was incredibly inefficient (0.03% efficiency) and could not be seen by the human eye.

The Science Behind the LED

To understand how an LED works you must first understand what insulators, semi-conductors and conductors are. In short, an insulator is a material that cannot conduct electricity, a conductor is a material that easily conducts electricity, while a semi-conductor is a material that has a conductivity in between those. An example would be rubber for insulators and copper for conductors. The fundamental principle behind the LED is passing an electrical current through a semi-conductor and producing light.

In each atom there are multiple "shells" that can house a specific number of electrons, with each shell requiring a level of energy for electrons to be in that layer and the energy required to be in a shell grows larger the further the shell is from the nucleus e.g. (Figure 2). The outermost shell of an atom is called the "Valence Band" with another layer above it called the "Conduction Band" which requires even more energy to reach. When electrons reach the conduction band, they are able to move freely. The gap of energy between the valence and conduction band is called the "Band Gap". In a conductor the band gap is small enough such that electrons can move freely without needing to gain much more energy while in an insulator the band gap is too large, so electrons won't be able to reach the conduction band and escape. However, a semi-conductor is special in that normally the band gap is too large for electrons to be able to jump between the two bands but when an electrical current is applied the electrons gain enough energy to jump this gap.

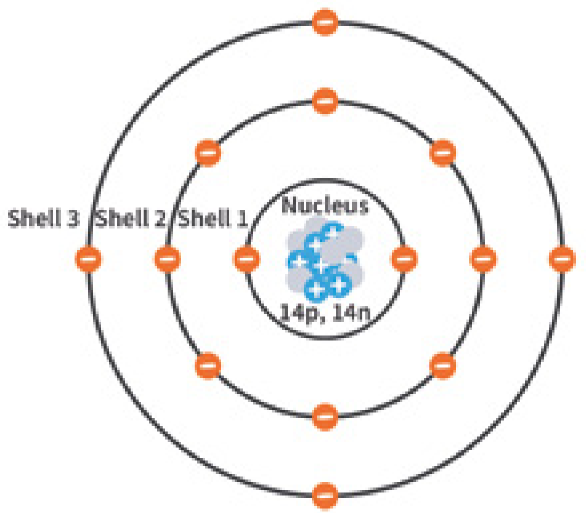

Figure 2: Bohr Model of a silicon atom.

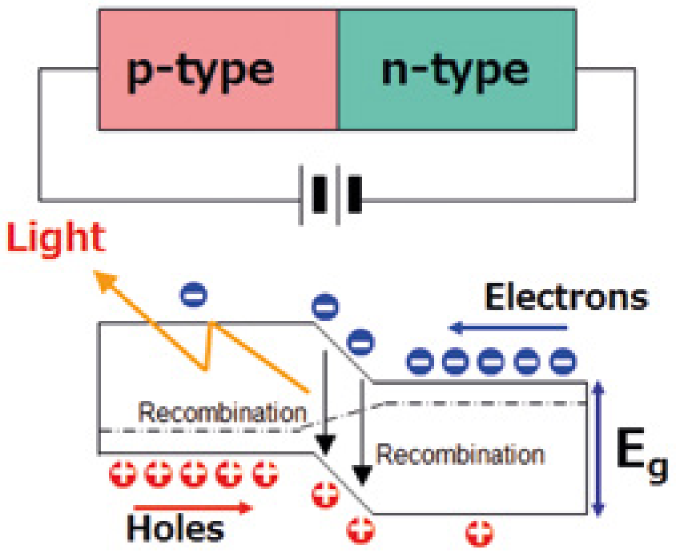

Figure 3: Diagram of a LED's Semiconductor

In an LED's semi-conductor there are two layers: the negatively charged layer often called the "N-type" which has an excess of electrons, and the positively charged layer called the "P-type" which has a shortage of electrons. These layers are both mostly made of the same material, but impurities are then added to each side to create the excess or shortage of electrons. Naturally the electrons from the N-type layer move into the P-type layer to fill the "holes" of the missing electrons. This happens until there is a sort of barrier stopping any sort of exchange between the two. This happens because as holes gather at the surface of the N-type layer, and electrons gather at the surface of the P-type layer it creates an electric field blocking any flow until a current is applied. Electrons jump from the N-type layer's conduction band to the P-type layers valence band and because the conduction band has a higher energy requirement than the valence band the leftover energy must be outputted some way, often as photons, which is how an LED's semi-conductor produces light (Figure 3).

Different materials can be used to make the semi-conductor such as silicon, and depending on which material is used, it will determine how large the band gap is. The higher the energy required to move between the valence and conductor band, the higher the energy outputted from the jump between P and N type and therefore, the smaller the wavelength of the light that is emitted which ultimately determines the colour of the light emitted. For example: Using a compound of gallium and phosphorus to make a gallium phosphide semiconductor, has a band gap just large enough that the light emitted when an electrical current is passed through is green. Materials can also be mixed together to "customize" their colour, an example would be a mixture of 60% gallium arsenic and 40% gallium phosphide to make a material that emits red light.

Conclusion

In conclusion, the LED is a clear example of modern ingenuity and creativity because of the century of hard work it took for it to become one of the most influential and important inventions today. It revolutionised how data and knowledge was shared across the world enabling things like fibre optic cables which are the backbone of the internet, and LED screens which display information. LEDs undoubtedly brought in a golden era of learning for us where now we can share findings with the world instantly with a click of a button when in the past it took weeks, months, and possibly even years for your information to reach international ears. Not only that, but they also made cheap and bright lighting affordable for every household and business.

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The history of gene editing technologies and the issues they present

Words by Noah Varghese (Year 11)

Thought starters

Gene editing technology is a highly specialised and valuable technology that could well be one of the most significant advancements in scientific research in the last 80 years. It has various applications in healthcare, agriculture, and others, however, several ethical issues exist.

This article will outline how gene editing technology works, its applications and ethical issues that arise from the use of this technology. Furthermore, this article will also compare and contrast various gene editing technologies to determine which one is preferable after considering the time and resources required, its cost and availability.

Gene editing technologies have developed over the years and have different processes to edit genes. In 1973, recombinant DNA technology was developed by Stanley Cohen and Herbert Boyer, which enabled scientists to take DNA from an organism and introduce it into another organism, essentially, the first type of gene modification. In the 1990s, Zinc Finger Nucleases (ZFNs) arose as another option. Fundamentally, these are special proteins able to target particular sequences of DNA, i.e., they are more precise than recombinant DNA technology. In early 2010, Transcription Activator-Like Effector Nucleases (TALENs) were created, which are similar to ZFNs, but they use a different mechanism in DNA-binding which allows for better flexibility and more precision. First developed in 2012, CRISPR-Cas9 was originally discovered in bacterial cells, which used this mechanism almost as a miniature immune system, to identify, kill and remember invading viruses. There are two key components of CRISPR-Cas9 technology and both play a vital role in the function of CRISPR. The first part is the guide RNA (gRNA), which is a short sequence of RNA, manufactured in a lab, that is complementary to a specific section of the target DNA. The other component is a Cas9 enzyme. The gRNA will guide the Cas9 enzyme to the specific sequence of DNA and the Cas9 will act as 'molecular scissors', cutting the DNA sequence, at that location.

Gene editing technologies have significant potential in multiple areas of science and have various applications in society. Firstly, they have countless applications for the treatment of diseases and other healthcare for humans. Humans with diseases that arise from mutations in their genome can undergo treatment using gene editing technology. In December 2023, the UK Medicines and Healthcare Products Regulatory Agency (MHRA) approved the use of CRISPR in the treatment of patients with sickle cell disease. This specific disease arises from a single base mutation in a genome which leads to red blood cells forming an abnormal 'sickle' shape, and therefore, unable to absorb and carry as much oxygen as healthy red blood cells. CRISPR-Cas9 can be utilised to identify and correct this error in the genome, therefore, it exists as a potential treatment. Furthermore, gene editing technologies can also be used for agriculture, to enhance plants and other crops to be improved or made resistant to diseases and various pests. Scientists can research genes that may affect the quality of crops, such as genes that would allow the plants to have greater resistance against diseases. Technology such as CRISPR can then be used to modify the genome of the plants and therefore, improve the crops and the quantity of crops yielded. An example of this is the first genetically modified banana approved for consumption in Queensland, Australia. Professor Dale from the Queensland University of Technology, genetically modified the bananas to be resistant to the deadly Panama disease. Additionally, in May 2024, China approved the first gene edited wheat plants to be grown, these crops are higher yielding which would increase the food security and generate significant benefit economic benefits for the country.

It should be noted that there are still certain limitations of this technology especially for CRISPR-Cas9. Some examples include how the Cas9 enzyme could potentially cut at the wrong location, there could be a mixture of cells that are treated and untreated, an intended immune response could be triggered, and negative impacts could be passed on to future generations. Furthermore, treating fully differentiated or adult stem cells with CRISPR-Cas9, is quite unusual, as it is quite difficult to correct mistakes in cells after they have differentiated. This means the technology can realistically only have a significant impact in embryonic stem cells, however, there are multiple ethical issues surrounding the use of these type of cells.

Numerous ethical issues arise from the use of this technology which some may argue is a deterrent for its use. Although this technology has been available for several years, further research is necessary to understand the full impact that gene editing may have. It is still not fully known whether side effects may occur if an organism is treated with gene editing technologies such as CRISPR, and if these problems may be passed on to future offspring. In addition, this technology may create further divisions between classes, as there are accessibility concerns of whether only wealthy people will be able to use this technology. Illegal research could also be undertaken, which may lead to mistreatments of humans or animals. An example of this was seen when a scientist in China used CRISPR on human embryos illegally, which caused serious concerns over the wellbeing of the children as CRISPR was still relatively new, and led to repercussions for the scientist that conducted these experiments. Furthermore, if this technology

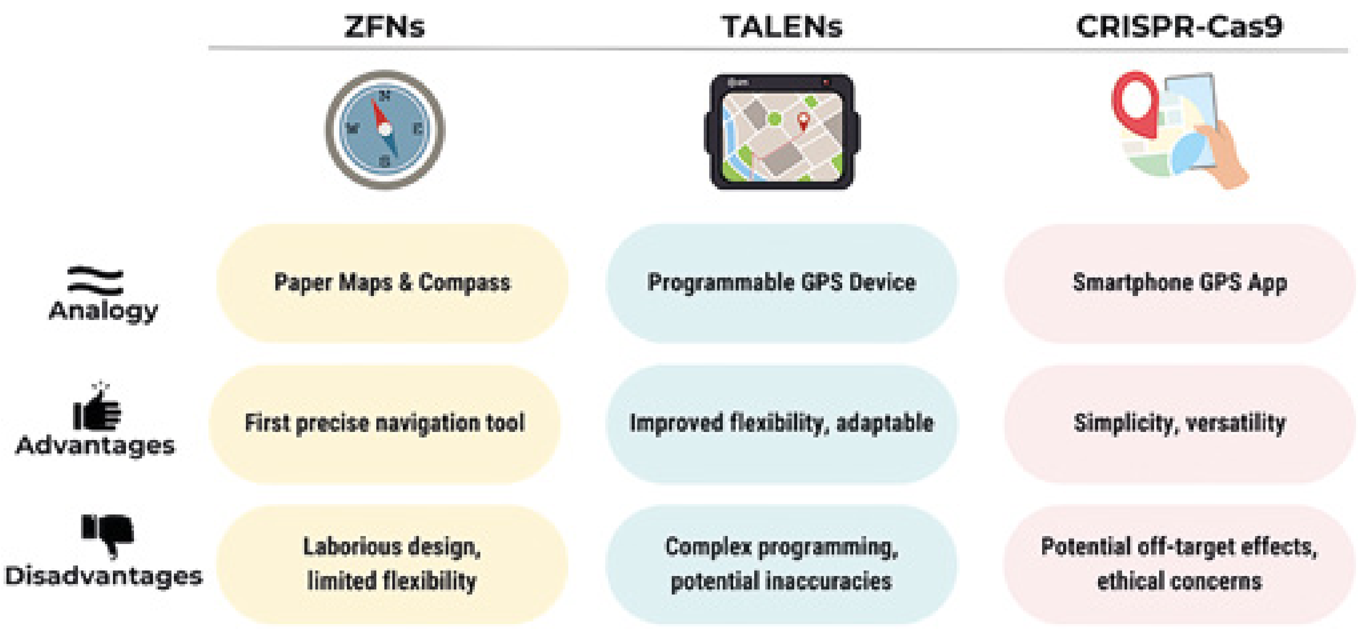

Figure 1 - A comparison of different gene editing technologies

develops to an extent where it is safe and widely used, another concern would be if people would modify themselves, or their offspring to their liking, even being able to create 'designer babies'. Likewise, it raises another question of how the offspring cannot consent to these changes, which creates even more concern. As explained above, CRISPR can only have a substantial effect in embryonic stem cells. These cells are achieved by fusing a sperm cell with an egg cell, and obtaining the inner cell mass of the blastocyst created after fertilisation. Some people argue that this process destroys the blastocyst, effectively, taking away 'an innocent life'.

The various methods of gene editing explored above, have several advantages and disadvantages. ZFNs have high target specificity and are well researched, yet a challenge presents itself in the fact that specific ZFNs must be developed for each target gene, which is a costly and laborious process. TALENs have a higher target specificity and more flexibility than ZFNs, yet the programming required is quite complex and there may be potential errors. CRISPR-Cas9 has the highest target specificity and is the most versatile technology as it can essentially target DNA sequences found in the genome down to a specific base, due to its gRNA component. However, it does have some limitations outlined above but especially around off-target effects, and unintended immune response. This comparison is outlined in Figure 1.

In conclusion, gene editing technologies have significant potential in multiple areas of science and society. Although they are relatively new and have some drawbacks, with more research they can be perfected and implemented safely. They do pose numerous ethical concerns which will need to be discussed on a global level, with restrictions and regulations that need to be placed. Currently, CRISPR-Cas9 would be the preferred gene editing tool as it is much more precise and offers greater specificity compared to other technology. Ultimately, gene editing technology are one of the most remarkable developments in the last 80 years of scientific research and are undoubtedly the future that the current and future generations will experience.

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1950s

Watson and Crick unveiled the double helix structure of DNA, unlocking the secrets of genetics in 1953

In vitro fertilisation: the revolution of human reproduction

Words by Sage Goel (Year 8)

Thought starters

Figure 1- Dr Robert Edwards and Sir Patrick Steptoe with Louise Brown and her mother

There is an old bell jar that sits atop a cupboard at the Cambridge Fertility Clinic. A testimony to the first baby born by *in vitro* fertilisation (IVF), Louise Brown. In 1978, she spent her first few hours of life inside this very vessel. Her conception; a direct result of the tenacity and prowess of IVF pioneers Dr Robert Edwards and gynaecologist Sir Patrick Steptoe, has become one of the most significant discoveries of the last 80 years in medicine.

IVF is a type of fertility treatment, whereby mature eggs and sperm are combined outside of the body (*in vitro*). Fertilised eggs (embryos) are then placed inside the uterus. In turn, creating a viable pregnancy.

Over the last two decades IVF has become increasingly popular. As of 2024 over 6 million babies have been born via assisted reproductive technology. In Australia 1 in 18 infants are brought into the world because of this procedure.

IVF is now considered one of the greatest scientific discoveries of our generation. Forever changing the landscape of human reproduction and forging the foundation on which millions of families have built their dreams

Louise Brown is now 46 years old, and what was once considered controversial has now become routine. In fact, at the time of Louise's birth, the idea of fertilising human eggs in a test tube was considered akin to playing God. So, how did research once thought taboo, result in the birth of a human baby?

The origins of IVF can be traced back to 1890. When Walter Heape, a physician at Cambridge University (United Kingdom), reported the first known case of embryo transplantation in rabbits. Then, in 1934, Pincus and Enzmann from Harvard University raised the idea that mammalian oocytes (eggs) could undergo normal development *in vitro*. Fifteen years later, Menken and Rock built on this idea, retrieving 800 eggs from women and successfully exposing 38 to human spermatozoa (sperm).

However, it wasn't until 1959, that indisputable evidence of IVF was obtained. When Dr Min Cheu Chang successfully used IVF to breed black rabbits. Following this breakthrough, interest in recreating these results in humans began to gather momentum, with scientists worldwide working tirelessly to achieve this goal. In 1973, the first human IVF pregnancy was reported at Monash University in Melbourne, Australia by Professors Carl Wood and John Leeton. Unfortunately, the conception resulted in an early miscarriage.

These results were observed with interest by Dr Robert Edwards and Sir Patrick Steptoe at Cambridge University. The researchers, who had been working together since the late 1960s, were eager to obtain funding to further their research into IVF. However, despite multiple grant applications to the Medical Research Council, they were denied funding. The reasons for this were largely political in nature. At the time many scientists believed that research using human eggs and sperm was unethical and immoral.

Steptoe and Edwards' were thus forced to set up a privately funded lab near Cambridge in Oldham. Here, they relied heavily on female volunteers to conduct their research. Sworn to secrecy, largely for their own well-being, the women involved in trials were encouraged not to make comment to the media. Such was the public indignation at the time.

Despite popular perception, Steptoe and Edwards worked tirelessly with couples desperate to conceive. Finally, in 1978, Louise Brown, the first ever IVF baby, was delivered at Oldham. Soon afterwards, in 1979, Alistair McDonald was born at the same laboratory.

The news of Steptoe and Edwards' success spread quickly. Across the world, scientists, eager to replicate these results, sought funding. Slowly but surely, the public's view of IVF began to change for the positive. The first IVF birth, outside of the United Kingdom, occurred in Australia at Monash University in 1980. A year later, the first IVF baby in the United States was delivered.

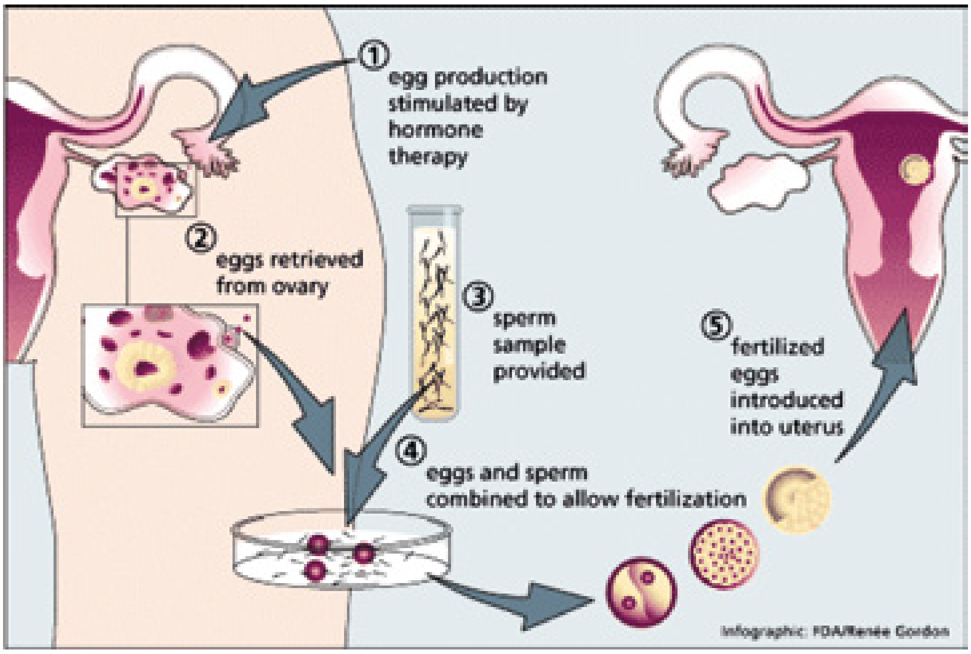

Figure 2- The process of IVF

In these early years success rates were low, averaging only 12%. To this end, most women who engaged in IVF in the early 1980s, did not end up with a baby. In addition, media scrutiny was high and the process itself, more laborious.

Much has changed over the last 30 years, as IVF technology has continued to advance. Today, eggs and embryos can be frozen for future use. In addition, the human genome project has allowed embryos to be assessed for numerous chromosomal abnormalities. While the advent of intra-cytoplasmic sperm injections (ICSI), has enabled the treatment of male fertility problems. The multiple birth rate, the biggest risk from IVF, has also reduced and the process of IVF is more streamlined than ever before.

IVF was initially developed to treat infertility. This can be defined as an inability to get pregnant after 12 months or experiencing two or more failed pregnancies. Infertility can result from a variety of causes. These include fallopian tube obstruction, ovulatory disorders, previous surgery to prevent pregnancy, and spermatozoa dysfunction. Endometriosis for example, is a common cause of fallopian tube blockage. While polycyclic ovary disease is associated with ovulatory dysfunction.

IVF use is indicated in cases of infertility where medications designed to induce ovulation have proved ineffective or are not able to treat the reproductive abnormality at hand. The exception to this rule is women aged 40 years and above and those with critically low ovarian reserve. In these circumstances, IVF may be used as a first line treatment.

Today, IVF is also commonly used in couples where there is a risk of passing on a genetic disorder. In this case, eggs and sperm are harvested and subsequently tested for genetic problems such as cystic fibrosis and Tay-Sachs disease. Embryos deemed healthy can then be placed into the uterus.

Although the technology for egg freezing has been available since 1986, it has only gained popularity since the turn of the millennium. Largely driven by increasing maternal age, women are now able to freeze and store their eggs in their 20s, until they deem parenthood appropriate. Both sperm and eggs can also be frozen when either partner is undergoing treatment that may impact the quality of their gametes, such as chemotherapy. Previously frozen eggs and spermatozoa can then be fertilised, and pregnancy achieved through IVF at a later date.

The ultimate goal of an IVF cycle is for a viable embryo to be placed inside a female's uterus. This is a complex procedure, which is best understood when broken down into sequential steps (see figure 2).

The first stage in the IVF process involves stimulating the female's ovaries to produce eggs. This is achieved by administering medications such as clomiphene on days 2 to 10 of a woman's cycle. These drugs block oestrogen receptors in the body, which in turn induces FSH (follicle stimulating hormone) production and the development of follicles within the ovary. GnRH antagonist medications such as cetrorelix are then commenced on days 6 to 8, in order to block ovulation prior to egg retrieval.

Egg recovery is conducted between days 12 and 14 of a woman's cycle. A day and a half before the procedure is conducted, an injection of FSH is administered to help the eggs mature. The eggs are then retrieved in a minor surgical procedure known as follicular aspiration. This is generally conducted in an outpatient setting under ultrasound guidance. In summary, a thin needle is inserted through the vagina and into each ovary. Eggs are then extracted by suction, one at a time.

Following this procedure, viable oocytes are fertilised by sperm within a culture medium. Specifically, a single sperm is injected by ICSI into each healthy egg using a microscope for guidance (Figure 3). In modern labs this procedure is conducted in an incubator at 37°C, in order to mimic the conditions of the human body. Once combined it takes 18 hours to determine if successful fertilisation has occurred and another 2 to 4 days to determine if a viable embryo has been produced.

After egg collection, progesterone injections are administered daily in an outpatient setting. This prepares the uterine lining for embryonic transfer. Healthy embryos, at this stage named blastocysts, are then inserted via a catheter into the uterus using ultrasound guidance. Where possible, multiple embryos are placed, in the hope that at least one will implant in the uterus. Sometimes more than one does, which is why multiple births are common in IVF.


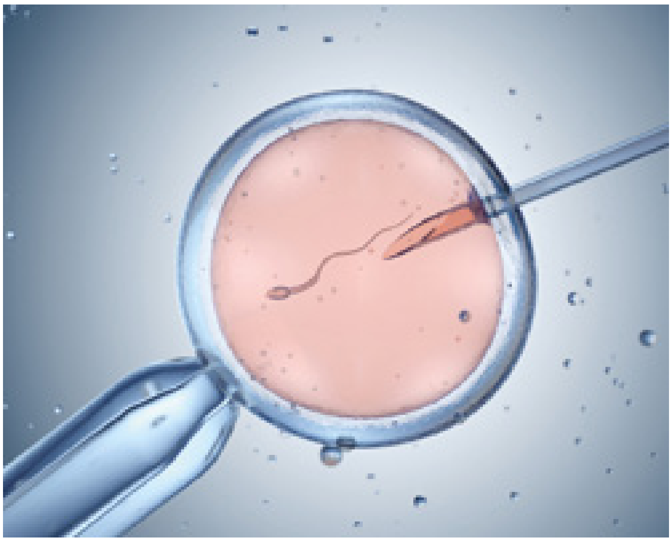

Figure 3- Intracytoplasmic sperm injection

A pregnancy test is then used to assess the success of the procedure. Essentially, IVF replicates the process of natural reproduction.

While the benefits of IVF treatment are clear, the procedure is not without its drawbacks. First and foremost, a treatment cycle may be unsuccessful. While this varies between individuals, studies suggest a cumulative success rate of approximately 50%.

In addition, IVF can take a significant emotional toll on those undergoing treatment. With the expectation of a positive result, the invasive nature of the procedure and administration of hormones all having a potentially negative effect on mental well -being. Physical health can also be impacted. High dose gonadotropin administration, which is required in IVF, is associated with a 3-6% incidence of ovarian hyper-stimulation syndrome. The disorder, in its severe form, can result in crippling abdominal pain, vomiting, diarrhoea and dehydration.

IVF treatment also requires a substantial financial outlay. With the cost per cycle averaging between 6000-10000 AUD. Furthermore, IVF pregnancies are associated with a higher risk of miscarriage, low birth weight, and a 30 fold increase in multiple pregnancies. A positive correlation with premature labour and stillbirth has also been observed.

IVF has been a source of ethical controversy since its inception. Those opposing the procedure have raised concerns around the disposal of embryos and put forward that fertilised eggs should be considered 'a life.' The potential of genetically testing gametes to create 'designer babies,' has also been raised. Furthermore, many have voiced concerns around the capacity of women to bear children at any age, using frozen eggs and IVF.

Despite these apprehensions, for most of the scientific community and broader population, the positives of IVF far outweigh the negatives. With the process allowing couples who would otherwise be unable to conceive, to expand their family.

Since 1978, 6 million babies have been born through IVF. Success rates, once in single digits, are now at 50%. Moreover, IVF technologies continue to advance, resulting in less risky and more streamlined procedures.

There is no doubt that Louise Brown's birth changed the face of reproductive medicine. Yet it was the determination of Steptoe and Edwards and the courage of their early patients that so many people have to thank for their families.

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How has the rapid spread of antimicrobial resistant bacteria influenced the development of nanotechnology?

Words by Aidan Foo (Year 11)

Biology

The prevalence and advancement of medication over the past century has led to bacteria adapting and creating resistance to multiple forms of antimicrobials, categorised as being antimicrobial resistant (AMR). By 2050, AMR could cause more than 10 million deaths at the expense of $100 trillion USD without intervention. New treatment options are currently being explored by scientists in response to these demands. Recent prospects to implement nanoparticles (NPs) to combat AMR are done by disabling and preventing the growth and spread of these bacteria.

Over multiple exposure cycles, bacteria can develop defence mechanisms toward a wide range of medications, leading to higher amounts/dosages required to kill each new generation. AMR bacteria can survive these cycles, as mutations allow adaptations for highly specific cell membranes, and mechanisms to remove antimicrobials. Bacteria initially recognise antimicrobials entering the cell through porin channels, and, in response, reduce the number of these porin channels, whilst also increasing the thickness of its cell wall. Encoded efflux pumps that are present in all bacteria typically function to rid the cell of toxic substances; however, bacteria can also adapt to recognise medications as foreign and remove them, siphoning unknown substances out.

To allow antimicrobials to function properly, various methods involving nanoparticles (NPs) are utilised to disable AMR properties of bacteria, such as disruption of their cell walls and membranes, production of reactive oxygen species (ROS), and interactions with intracellular processes. These technologies have proven to hinder the growth of AMR 22 times more effectively compared to conventional treatments. The cell membranes and walls of AMR contain teichoic acids and lipopolysaccharides that ensure the surfaces of bacteria are negatively charged, altering the hydrophobicity and diffusion of antimicrobials into their cells. Therefore, cationic charges and hydrophobicity of nanoparticles can be adjusted accordingly. The subsequent electrostatic attraction created between oppositely charged particles allows for spatial aggregates to form on bacterial membranes (see Figure 1). This membrane disruption allows for antimicrobials to properly enter and alter the cells' structure, resulting in its death.

Reactive oxygen species (ROS) are the by-product of oxidative metabolic processes that control cellular processes. However, nanoparticles promote excessive levels of ROS, creating more fluid cell membranes and lethal oxidative stress levels, which kills cells (see Figure 2). NPs can also be engineered to obstruct metabolic pathways by disrupting bacterial DNA, gene expression and protein synthesis (Figure 2). The synthesis of pyrimidine-capped AuNPs can completely

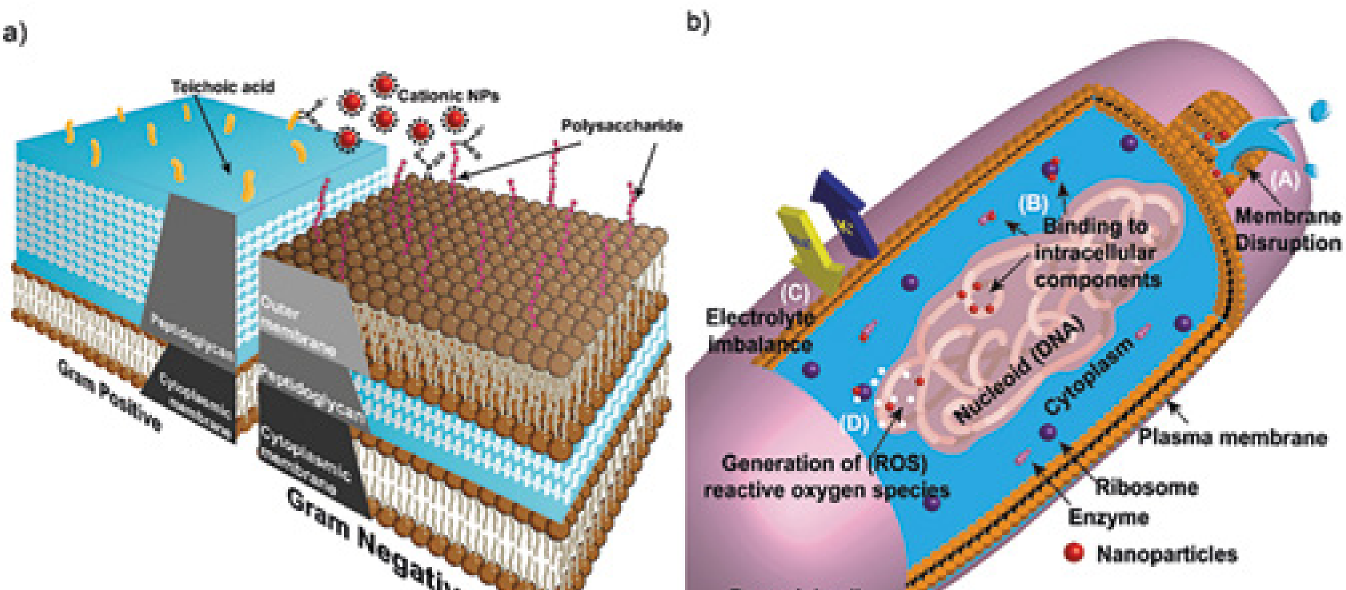

Figure 1: Nanoparticles forming spatial aggregates on cell walls and membranes

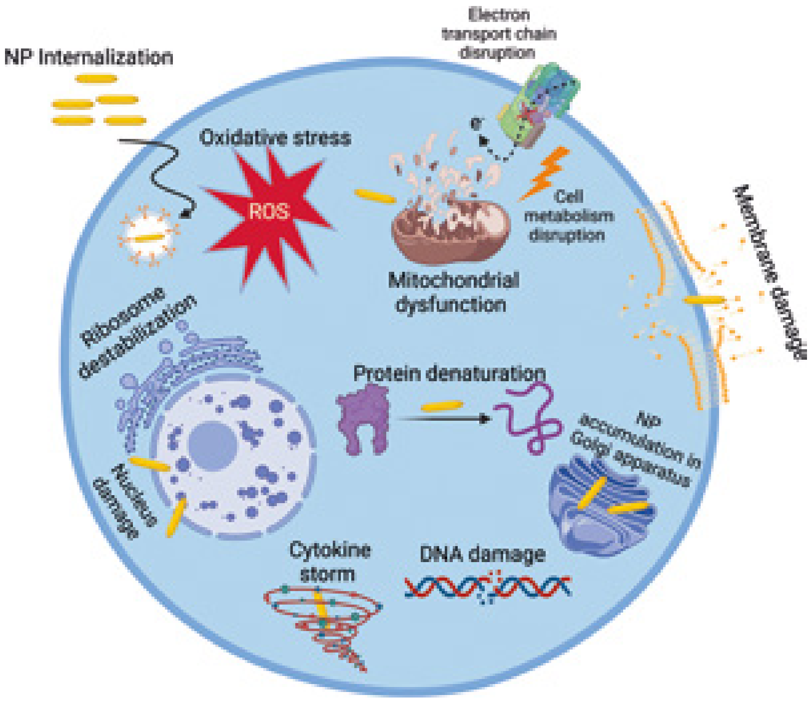

Figure 2: Nanoparticles (NP) causing increases in reactive oxygen species (ROS) and their impacts on cellular processes

inhibit the reproduction of some species of bacteria. Using electroporation or spatial aggregates to successfully enter cells, nanoparticles attach to ribosomes, preventing t-RNA binding and the inhibition of protein synthesis. AgNPs and MgONPs are also known to be able to reduce the rate of metabolism for vital amino acids and mutate.

Given the severity of AMR due to the irresponsible usage of antimicrobials in various healthcare sectors, more than 75% of all human diseases can be traced back to animals, many of which carry AMR bacteria. The collaboration between the World Health Organisation, the World Organisation for Animal Health, and the Food and Agriculture Organisation have aided in the formation of a group designed to ensure global health security, called One Health. Human, animal and environmental health sectors have been used to accelerate the formulation of potential solutions to zoonotic diseases. This group will be crucial to avoid the inevitable social disparities in society that will appear between high and low-income countries, where low-income countries automatically become more susceptible to consequences of AMR due to poor access to treatment options. Low-middle income countries such as Algeria, Tunisia, Romania, and Turkey already have some of the highest rates of antimicrobial usage in the world, with the ability to purchase antimicrobials without prescriptions and the high number of counterfeits available leading to the drastic spread of AMR. One Health plans to ensure extra resources are allocated for these countries.

Furthermore, cooperation requires heavy expenditure to carry out processes such as disease management, monitoring, regulation of policies and investment into research resources. Even though the projected annual spending won't exceed 10% of the potential that could be saved, One Health still struggles with the enormous funding required for clinical trials, production, and distribution costs, which all hinder the possible effectiveness of nanotechnology. It is anticipated that the formation of this group will allow for regulated usage of nanotechnology to establish the correct infrastructure and information for future nano-pharmaceutical companies to easily access and expand upon current systems, further ensuring public health security for all, and preventing future risks of AMR outbreaks.

In 2016, the United Nations declared antimicrobial resistance as a global health issue. With the global usage of antimicrobials

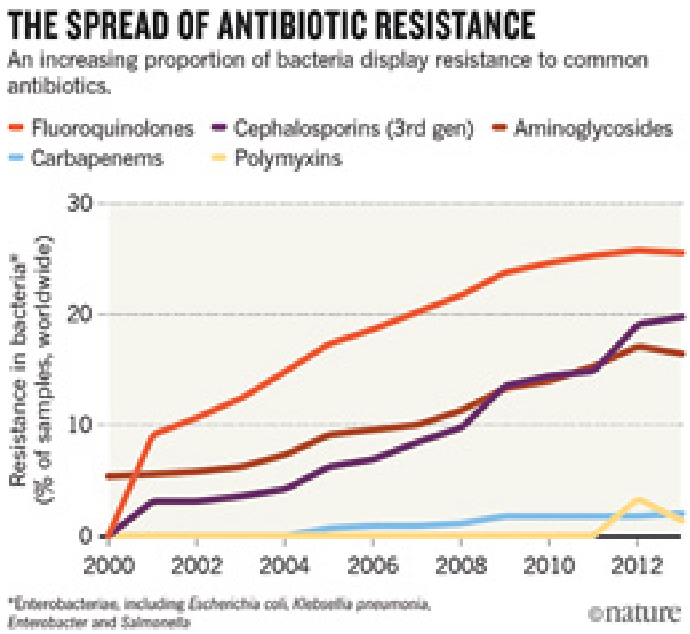

Figure 3: Trend of increasing AMR worldwide

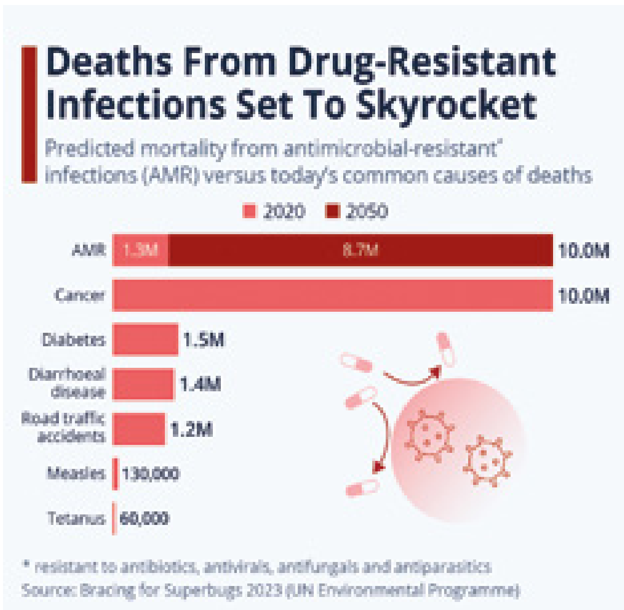

Figure 4: Projected death toll of AMR by 2050 without intervention compared to common causes of death

increasing by 65% between 2000 and 2015, it has drastically accelerated the growth of AMR (see Figure 3). Utilising nanotechnology could save the global economy more than $55 billion annually, and almost US$16.7 trillion by 2050. Currently low and middle-income countries are at the highest risk of AMR due to the common lack of resources and inadequate healthcare regulations and systems in place. In Nepal, more than 50% of healthcare is out of pocket expenditures and up to 80% in private hospitals. This price-gouging could continue if nanotechnology were to be implemented where poor governance and regulations can result in unequal distribution of medication for treating AMR, compounding the stress upon labour forces, sickness, and premature mortality rates. Billions of dollars could potentially be squeezed out of international economies and given to big corporations, creating a dysfunctional economy. AMR has already to lead to 1.3 million deaths in 2020 alone, and many of these current and future cases could easily be prevented with the implementation of nanotechnology, saving millions of lives (see Figure 4).

Moreover, AMR currently generates additional stress on healthcare systems with secondary effects such as the inability to use antimicrobials to treat patients that are at high risk of infection. Studies performed by Santoro-Lopes and de Gouvea found that AMR increases the likelihood of organ transplant failure and death of patients. For example, chemotherapy patients with AMR are unable to receive treatment, as their immune systems are at much higher risk to common infections. Without the usage of effective antimicrobial medication, this inability of patients with AMR to be treated effectively significantly decreases their chances of survival, even from minor infections. This further exacerbates pressure felt by the healthcare system, which requires additional support and resources to care for patients that are now more unwell due to AMR, costing hospitals valuable time and money that should be used to care for the wider majority of patients instead. This ultimately negatively impacts global healthcare systems.

WHO has currently identified 27 AMR technologies in development, with some involving nanoparticles. Many companies see vaccines as one of the most effective forms of treatment using nanoparticles, as they are able to reduce dependence on antimicrobials by decreasing common symptoms of infection. Clinical trials and vaccines are being developed by numerous companies such as ARIKAYCE® to treat lung disease refractory, Aridigm Corporation to treat non-cystic fibrosis bronchiectasis and Wyeth Pharmaceuticals to treat rare strains of pneumonia. All these technologies have been FDA approved, and their nanotechnologies are already in circulation. Moreover, nanomaterials are also set to be incorporated into coatings, plastics, gels, implants, and wound dressings. In 2020, The Australian Government pledged $22.5 million to address the concerns of AMR and formed a national One Health project in Australia. This has allowed experimental trials to be conducted at UniSA and RMIT, concluding that this treatment can eliminate 99% of all bacteria without harming other biological processes within the body. Although investors are attempting to raise funds for nanoparticle development, the formal processes for approval of new medical technologies are long and tedious, where all TGA and Quality Control Regulations must be met. Furthermore, the currently approved nanotechnologies are only viable alternatives for patients with limited treatment options who are at the highest risk of AMR, as the cost to treat the general public is currently unsustainable. While promising, applications of nanotechnology in healthcare to treat AMR still requires more time and development before it is truly ready for wide-spread usage.

Overall, discoveries into nanotechnology have opened many possibilities for new methods to combat antimicrobial resistance. Current risks in financial and public health safety have led to investigations into ground-breaking solutions. Even with complications in commercialisation for wide-spread public use due to heavy regulations and clinical trials required, it looks to be one of the most promising solutions that are available to an ever-increasing problem. Nanotechnologies versatile options for disabling bacteria makes it functional, efficient, and capable of solving another impending healthcare crisis.

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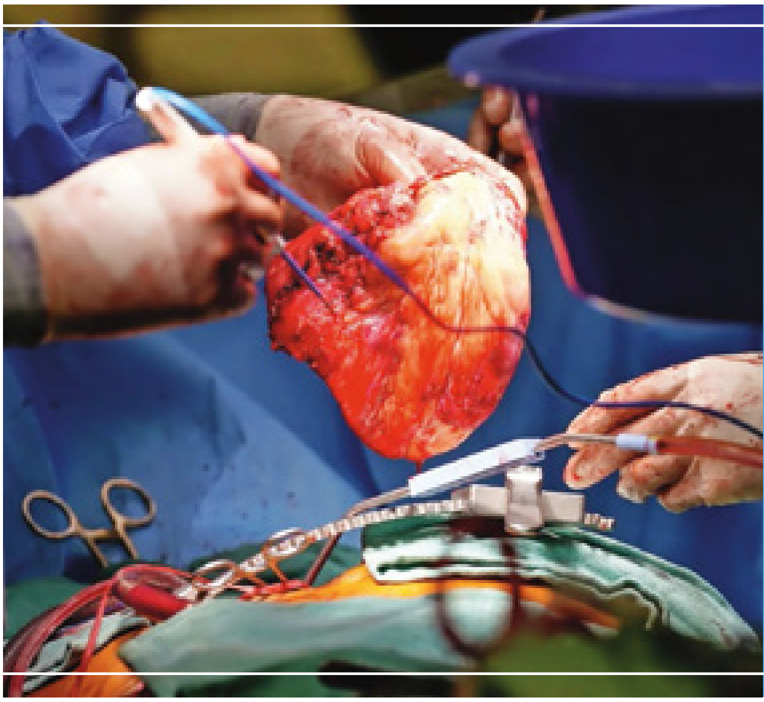

1960s

Dr. Christiaan Barnard performed the first successful heart transplant, changing the game for organ donation

The use of bioluminescent biomaterials in industrial engineering

Words by Aidan Obst (Year 11)

Biology

In order to maintain a safe working environment, the requirement for stress sensors in industrial occupations has become increasingly important. University of California San Diego has conducted a study into a luminescent biomaterial containing dinoflagellates which is able to respond to stress stimuli, for example, pressure or stretching, within 15-20ms. By combining both living and non-living components, scientists are able to develop new forms of self-sustaining materials, which can be applied to resolve previous challenges in a variety of different contexts.

The initial structure of these bioluminescent biomaterials consists of an alginate hydrogel base. This material is extracted from brown seaweed and is favourable for usage as it is biocompatible. This is because its structure is similar to that of organic tissues, hence allowing for cells to be transplanted into it, whilst still being able to function. When Ca^{2+} is added to the alginate, the material becomes gelatinous, allowing for the dinoflagellates to be mixed with it, (Figure 1).

The algae used for the material is a type of dinoflagellate called *Pyrocystis lunula*, (Figure 2) which can illuminate through a chemical reaction, in which the enzyme luciferase catalyses the oxidation of luciferin, producing oxyluciferin, which is what causes the algae to emit blue-coloured light.

While in the material, the algae are still able to photosynthesise, which not only allows the algae to remain alive, but also retain its bioluminescent properties which are crucial for the material's function. Additionally, an important function of the algae is that it only glows when disturbed, which is what allows it to be used as a stress sensor.

A variety of applications arise by implementing dinoflagellate stress sensors into engineering, including the benefits of using a living organism, its unparalleled detection abilities, its low energy requirement, and its potential versatility. An important benefit of the biomaterial is that it is a living organism, meaning it can self-sustain through the process of photosynthesis. This is crucial as the stress sensor would require no external electrical power source to function. This makes it more economical. Additionally, the material possesses an impressive detection ability and accuracy, sensing pressure as low as several pascals, and has an average response time of 15-20ms. As shown in Figure 3, the algae can detect various kinds of pressure with consistent accuracy. Even when faced with low-weight items such as the foam ball, a clear trail is still shown. This ultrasensitive behaviour is extremely useful for engineers, not only for the accuracy of the detection, but also because the glowing nature of the algae allows any flaws to be seen clearly.

This advancement in biomechanics has the potential to be useful in a variety of other areas. For example, when administering medicine, the light-emitting nature of the algae could be paired with light sensors to assist in precise drug release.

However, the dinoflagellate stress sensors also possess limitations for usage in an occupational setting, especially the algae's living conditions, and the stability of the hydrogel it is contained in. Firstly, even though being a living material assists in many ways, this also poses issues. The algae are required to undergo photosynthesis to survive, which means they require a stable supply of water and sunlight. This can cause issues to any projects which are covered from sunlight, or where water is difficult to supply. Additionally, the algae used in the material, *Pyrocystis lunula*, can only survive between temperatures ranging from 18-27˚C, and it cannot withstand extreme conditions. This poses difficulties regarding where these materials can be used, as temperature monitoring systems or protection for the sensor may have to be utilised

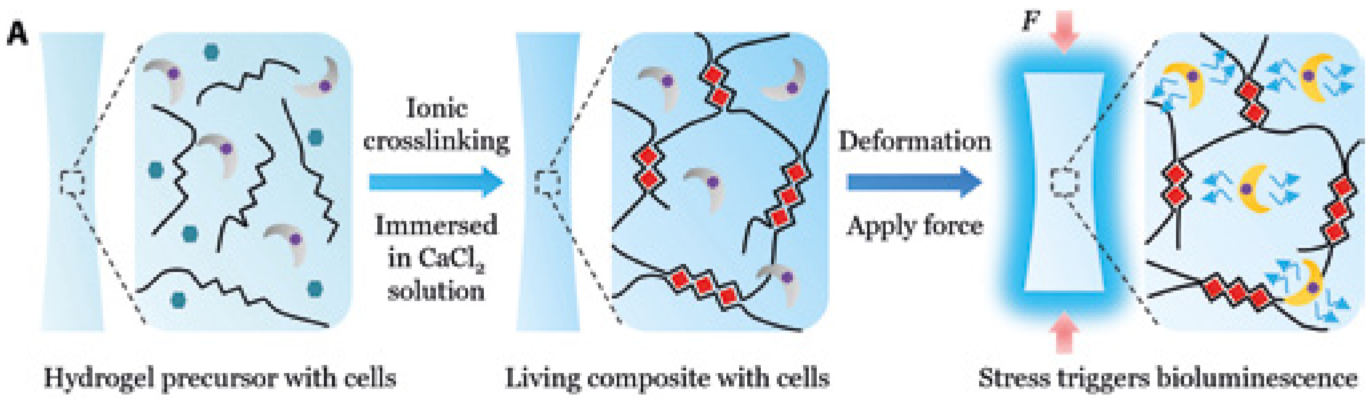

Figure 1: How the hydrogel and algae material is fabricated, and utilised.

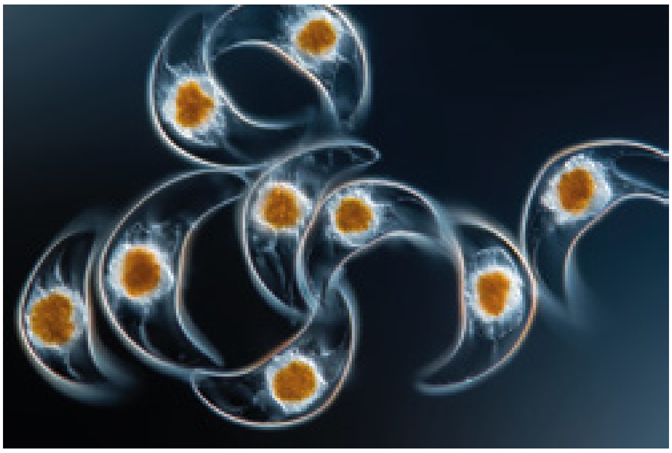

Figure 2 *Pyrocystis lunula*

if the conditions are suboptimal. Furthermore, the hydrogel in which the algae resides has shown evidence of gradual deterioration when being constantly loaded and unloaded, resulting in the light emissions from the algae changing slightly. This can be detrimental for light sensors, which would cease to recognise the illumination if the light changed too drastically, adversely impacting effectiveness.

In conclusion, the incorporation of dinoflagellate stress sensors into a variety of occupations will have clear benefits such as the sensor not requiring an external power source and its extreme accuracy to all forms of pressure. However, the technology is in its infancy, meaning more research is still needed to refine the material, such as its adaptability to environments, and supply of nutrients for the algae. Overall, whilst the utilisation and research of bioluminescent biomaterials continues to evolve, they represent a significant breakthrough which has opened paths for future scientific advancement.

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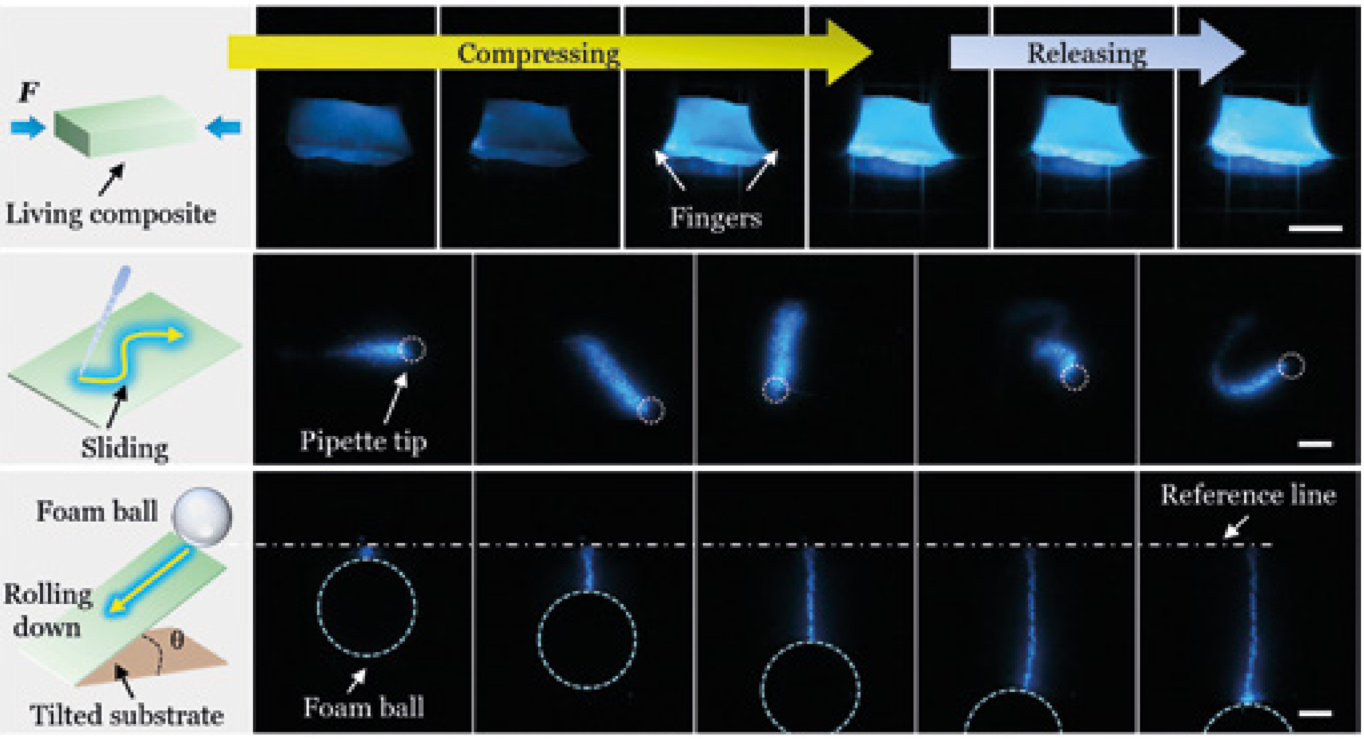

Figure 3: Testing and application of the algae, displaying bioluminecent ability

The science of aging

Words by Caleb Tang (Year 12)

Biology

The discovery of telomeres, which was awarded a Nobel Prize in Physiology and Medicine in 2009, has revolutionized our understanding of cellular aging. First identified in 1982, a telomere is a region of repeated non-coding DNA sequences at the end of a chromosome, and they are a fundamental part of all modern models and applications of DNA replication. Telomeres are found in most eukaryotic organisms and are responsible for protecting the ends of chromosomes from becoming frayed, tangled, or damaged (see Figure 1). This allows chromosomes to maintain their stability, whilst preventing loss of genetic information over time during DNA replication. Thus, telomeres play a vital role in preserving the information in our genome.

Unlike with circular prokaryotic chromosomes, the linear shape of eukaryotic chromosomes means that DNA at the end of the chromosome cannot be fully copied during each 'round' of DNA replication. Without telomeres, this would result in a very slow and gradual shortening of the chromosome, and thus loss of genetic information, over time. This is due to the double stranded nature of DNA, whereby unlike the leading strand, in which DNA is replicated continuously at a single replication fork, the lagging strand is produced discontinuously in many small pieces, known as Okazaki fragments, each beginning with its own RNA primer attached to the template strand, to maintain the 5'-3' direction of polymerisation. These RNA primers on the lagging strand should then be replaced by DNA bases via phosphodiester bonds, and the fragments joined together by DNA polymerase I and DNA ligase to form a single continuous strand. However, in some species, including humans, when the replication fork reaches the end of the chromosome, there is a short stretch of DNA that does not get covered by an Okazaki fragment. This is because formation of phosphodiester bonds when RNA primers are replaced by incoming DNA nucleotides relies on the hydroxyl group at the 3' end of neighbouring Okazaki fragments (see Figure 2).

However, at the ends of linear chromosomes, there are no neighbouring Okazaki fragments to provide the required hydroxyl. Without this hydroxyl group, DNA polymerase III has nothing to 'hook' onto and attach nucleotides to, thus resulting in incomplete replication of the ends of the chromosome. Consequently, sections of the DNA at the end of eukaryotic chromosomes go uncopied in each round of DNA replication, resulting in a single-stranded 'overhang'. As DNA replication continues, this process will repeat, and chromosomes will gradually become shorter and shorter (see Figure 3).

Telomeres exist to prevent this gradual loss of genetic information as ends of chromosomes wear down. These specialised DNA 'caps' consist of thousands of non-coding short tandem repeats, with the code 5'-TTAGGG-3' in humans, which essentially act like a buffer that protects the important

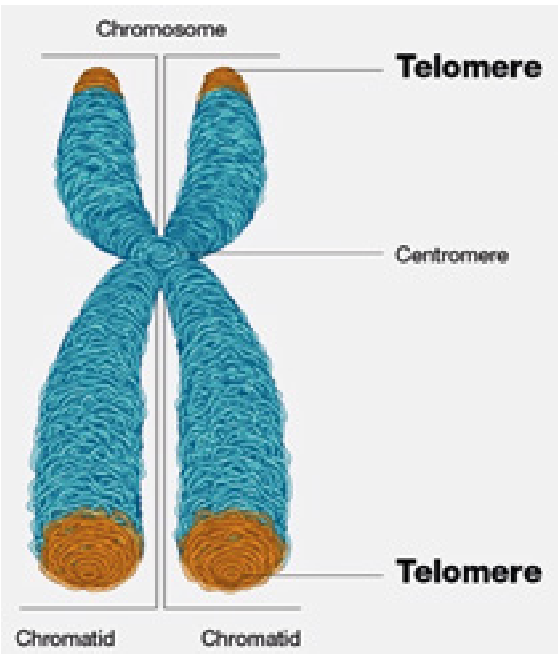

Figure 1: A eukaryotic chromosome, showing the sites of the telomeres.

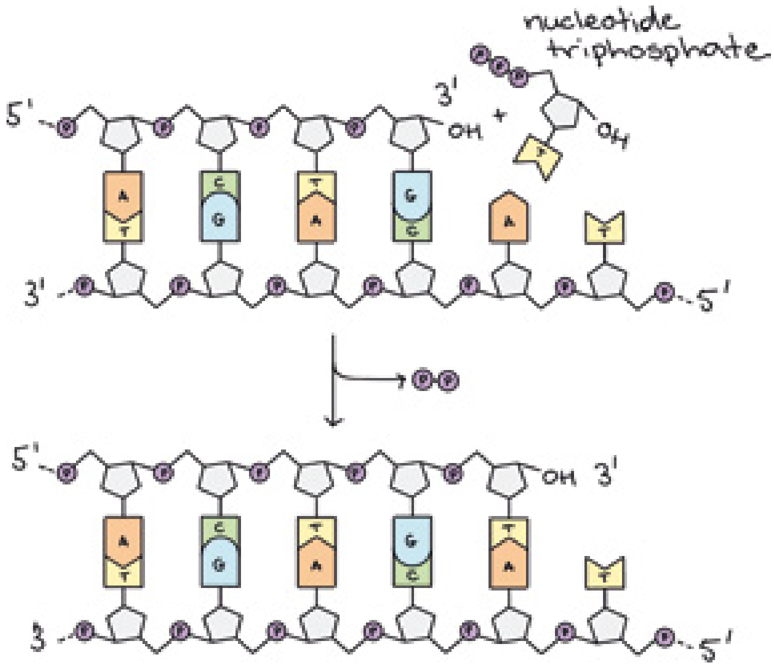

Figure 2: Mechanism for formation of phosphodiester bonds during DNA replication which joins nucleotides together.

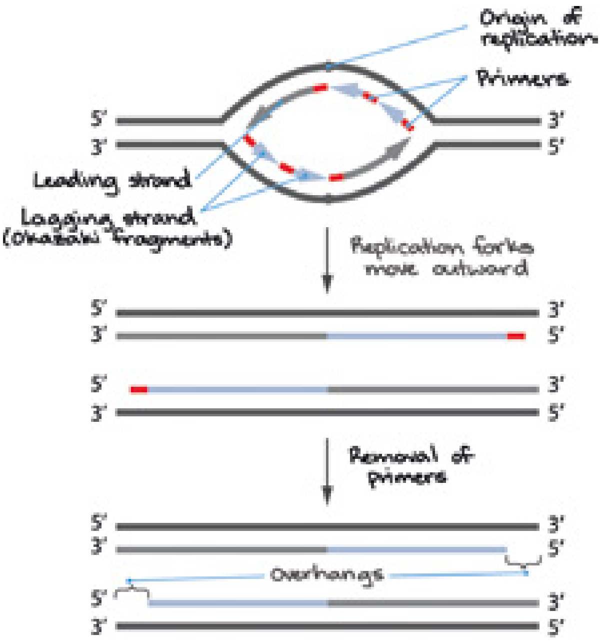

Figure 3: Mechanism for formation of overhangs due to incomplete replication of DNA at the ends of linear chromosomes, which results in a gradual loss of genetic information over time.

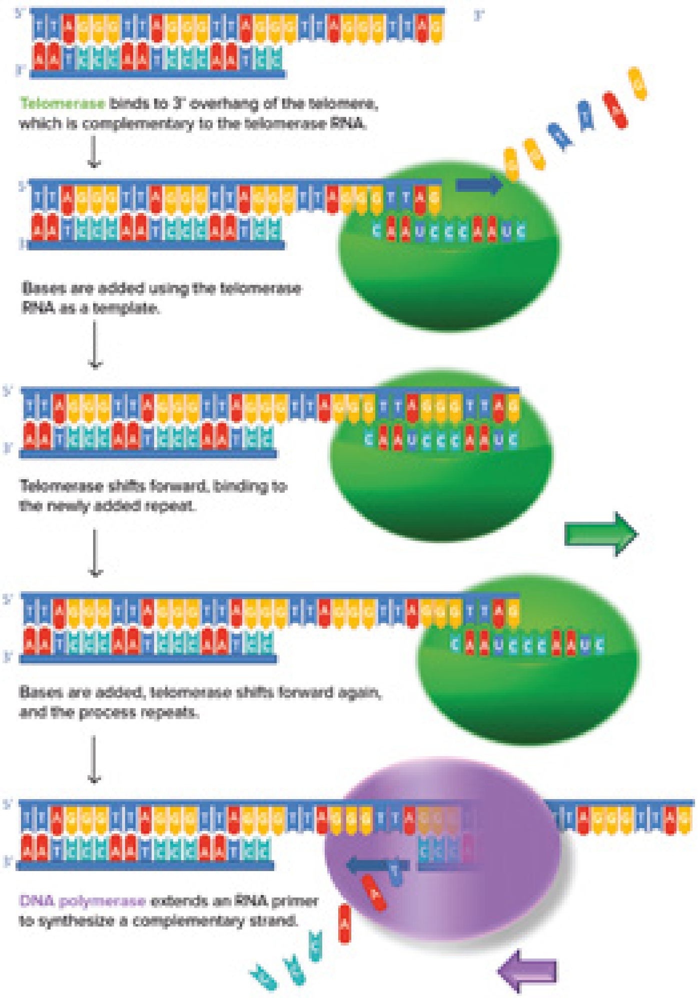

Figure 4: The role of telomerase in restoring telomere length and maintaining the protective buffer.

internal chromosomal regions which bear the genes, preventing loss of genetic information over time. Neverthel with enough cell divisions and DNA replications over time, telomeres may also be eroded away, leaving the important internal regions of chromosomes exposed and potentially becoming damaged. Some lifestyle factors such as smoking, obesity, lack of exercise, and consumption of an unhealthy diet have also been linked to increasing the rate of telomere shortening. Scientists currently believe that shortening of telomeres over time is linked to the aging of cells, and that the progressive loss of telomeres may explain why cells can often only divide a certain number of times.

Some cells in the body express the enzyme telomerase, which extends the telomeres of chromosomes and reverses telomere shortening. It essentially works by binding to a specific RNA molecule that contains a sequence complementary to that of the telomeric repeat, i.e., 5'-AAUCCC-3.' It can then use this complementary RNA as a template strand to produce the telomere DNA, allowing it to add nucleotides to the overhang of the telomere (see Figure 4).

The discovery of telomeres represents an enhanced understanding of a fundamental cell mechanism particularly relevant to human aging, as well as how genetic information is preserved, and how mutations in telomere and telomerase-related genes can lead to various diseases. This has stimulated the further development of new diagnostic and therapeutic techniques. For example, previous research into and surrounding telomeres has discovered that measuring telomere length can be used as a biomarker for aging and disease, with shorter telomeres being a sign of aging and onset of various diseases. Evaluation of telomere length in the elderly suggests that those with shorter telomeres have significantly higher mortality rates than those with longer telomeres. Of people older than 60, those with shorter telomeres are, according to Geneticist Richard Cawthon from the University of Utah, three times more likely to die from heart disease and eight times more likely to die from infectious disease.

Another finding which has emerged from the discovery of telomeres is the association of the genetically inherited disease dyskeratosis congenita with people who have been clinically diagnosed to have telomeres which become shortened over time much more quickly than those with normal telomeres. This often leads to premature aging and death, as well as higher risks of developing various associated diseases, such as leukaemia and other blood cancers, intestinal disorders, cirrhosis of the liver, and pulmonary fibrosis. Furthermore, dyskeratosis congenita causes a greater likelihood of greying of hair, balding, poor wound healing, softening of the bones, and learning disabilities. There is also some evidence linking shortened telomeres to Alzheimer's, hardening of the arteries, high blood pressure, and type 2 diabetes.

Emerging therapies are exploring methods to manipulate telomere length to treat or prevent these diseases. Various drugs are currently being developed to attempt to regulate the activity of telomerase, which could be used to help treat these telomere-length related diseases, in the belief that we can potentially extend our lifespan by artificially preserving and/or restoring the length of telomeres with telomerase.

However, high telomerase levels have also been linked to development of cancer. This is because it has been found that as a cell begins to become cancerous, it will often divide more frequently, leading to its telomeres becoming progressively shortened. If telomeres get too short, the cell may undergo senescence, or die. To counteract this shortening process, emerging cancer cells produce increased amounts of the telomerase enzyme, which prevents further shortening of the telomeres and allows for further replication of the cancer cells. Consequently, large amounts of research are also currently being directed towards producing medication that could inhibit telomerase as part of cancer therapy. This could prevent the excessive division of cancer cells, and thus the growth of the cancerous tumour. However, some studies have revealed side effects of blocking telomerase, such as impairing fertility, wound healing, and production of blood cells and immune system cells.

Evidently, telomeres and telomerase play a contradicting role in aging and the development of cancer. Increasing telomerase could reduce prevalence of various age-related diseases, however, also increases the risk of the development of cancerous cells and other side effects. The discovery of telomeres has stimulated further research surrounding whether treating age-related diseases by increasing telomerase could increase risks of cancer, and vice versa, and ultimately how humans can most effectively alter and modify our telomeres to improve our health outcomes.

One area of research derived from the discovery of telomeres surrounds *in vitro* applications of telomeres and telomerase – particularly their potential to be used in mass production of long-lasting, healthy cells, which can be used in transplantation. This could include transplantation of insulin-producing cells that could cure diabetes, muscle cells for treating muscular dystrophy, cartilage cells for certain kinds of arthritis, and skin cells for healing severe burns and wounds. This *in vitro* production of cells utilising artificial telomerase would essentially supply an unlimited source of normal human cells grown in the laboratory and could also be used for testing of new drugs and genetic modifications.

Ultimately, telomeres play just one role in the aging of humans, but an increasingly significant one. The human lifespan has increased considerably since the 1600s, when the average lifespan was 30 years – in 2024, the average Australian life span is currently over 84, and most scientists predict average life expectancies will continue to rise globally. As humans collectively continue to age, this has led to an increased risk factor from shortening of telomeres and cellular aging. Continued research into telomeres will undoubtedly provide us with a clearer picture of why this happens, and ultimately help us achieve better health outcomes.

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1970s

The rise of personal computers revolutionised how we work and play, putting technology at our fingertips

Eutrophication and possible solutions

Words by Charles Tang (Year 9)

Biology

Figure 1- Mississippi Watershed

Eutrophication starts with a surplus of nutrients reaching a body of water. This causes algal blooms, where the surface of the water is covered in algae. This film of algae blocks sunlight, preventing aquatic plant growth. The algae eventually dies and is broken down by bacteria, who release carbon dioxide (CO_2). The water also now lacks oxygen (hypoxic) and a process called ocean acidification occurs, where due to the increased CO_2, which is in equilibrium with carbonic acid, the pH of the water decreases.

Ocean acidification slows the growth of fish and shellfish and can prevent shell formation in bivalve molluscs (shellfish with a two-part hinged shell, like an oyster or mussel). In addition, fish are unable to swim away, and die due to the lack of oxygen, further disrupting the natural ecosystem. Because of this depletion of sea creatures, eutrophication destabilises the ecosystem, placing many species at risk of extinction. For example, Long Island Sound could lose all of its seagrass beds by 2030, and two-thirds of the Sound could lack enough oxygen for fish to survive. Furthermore, as a result of this eutrophication, commercial shellfisheries have lost millions of dollars annually since 1985 and due to the subsequent of seafood shortage, the associated industries have also suffered, with processing, restaurant, hospitality, and tourism industries all being impacted.

The Gulf of Mexico is bordered by 5 southern states of the United States, 5 Mexican states, and one Cuban state. Every summer, the second largest dead zone in the world, an area experiencing hypoxia, forms there. It ranges from about 15,000 to 18,000 km^2 in size, fluctuating seasonally due to farming practices and weather events such as flooding and hurricanes. In 1950, 50 coasts worldwide were reported to experience hypoxia, whereas now according to Milman, at least 500 sites experience hypoxia with the true number probably much higher. This results in millions of acres of habitat becoming unavailable to fish and other aquatic species. This dead zone will continue to damage the ecosystem and threaten some of the most productive fisheries in the world unless the pollution entering the Gulf is reduced. The Mississippi River Basin's watershed drains much of the US (Figure 1). Most of the nitrogen input comes from major cropping states in the Mississippi River Valley, (Figure 2). Nitrogen and phosphorus enter the river through upstream fertiliser runoff, soil erosion, animal wastes and sewage. Naturally, none of these are significant factors in eutrophication, but anthropogenically increased nitrogen and phosphorus input allows algae to grow much more, as the nutrients are no longer depleted in the soil by plants. Consequently, algae blooms develop, the water becomes hypoxic and acidic, altering food chains.

In 2001, a plan to reduce hypoxia in the Gulf of Mexico and inland waters was developed by the Mississippi River/Gulf of Mexico Watershed Nutrient Task (WNTF). The plan aimed to reduce the average area of the hypoxic zone to $<500km^2$ by 2015. This reduction was estimated to require a 60% decrease in nitrogen loading from the Mississippi River. Since 2001, millions of dollars have been invested into conservational projects across the Mississippi River Basin for measures such as wetland restoration, cover crops and riparian buffers, for areas adjacent to a body of water such as a stream, lake or wetland containing trees, shrubs and other perennial plants. However, despite these interventions, the hypoxic zone in 2015 was three times the goal size, and the target year has since been pushed back to 2035.

To minimise eutrophication, farmers are beginning to use more effective and efficient fertilisers to reduce runoff. Additionally, floodplains are being reconnected to rivers, which not only helps lessen floods, but also filters excess nutrients from the water. Furthermore, cover crops are being implemented. Cover crops are where during the off-seasons, farmers plant other crops on the otherwise vacant land. During winter and spring when a lot of rain falls, many US farms tend to be bare. The rainfall would generally tend to wash away all the nutrients and soil, however with the implementation of cover crops, their roots would hold the soil in place, slowing runoff and absorbing more nutrients, thus improving soil quality. Cover crops increased by 50% between 2012-2017, from 10.3 million acres to 15.4 million acres, however that was still only 4% of American farmland. In one small watershed in northern Indiana, 70% of the fields had cover crops planted. Runoff from these fields reduced by half, reducing the amount of nitrate entering waterways by 20% and phosphorous by 70%. However, to cover slightly over 320 hectares of land with these crops already required large amounts of money and time, so it would be difficult to scale to the Mississippi River Basin, which is over 900 thousand times larger.

Other solutions to eutrophication include wastewater treatment plants (WWTP) construction of wetlands, which minimise use of fertiliser and using phosphate-free cleaning products. WWTP's help to remove additional nutrients out of

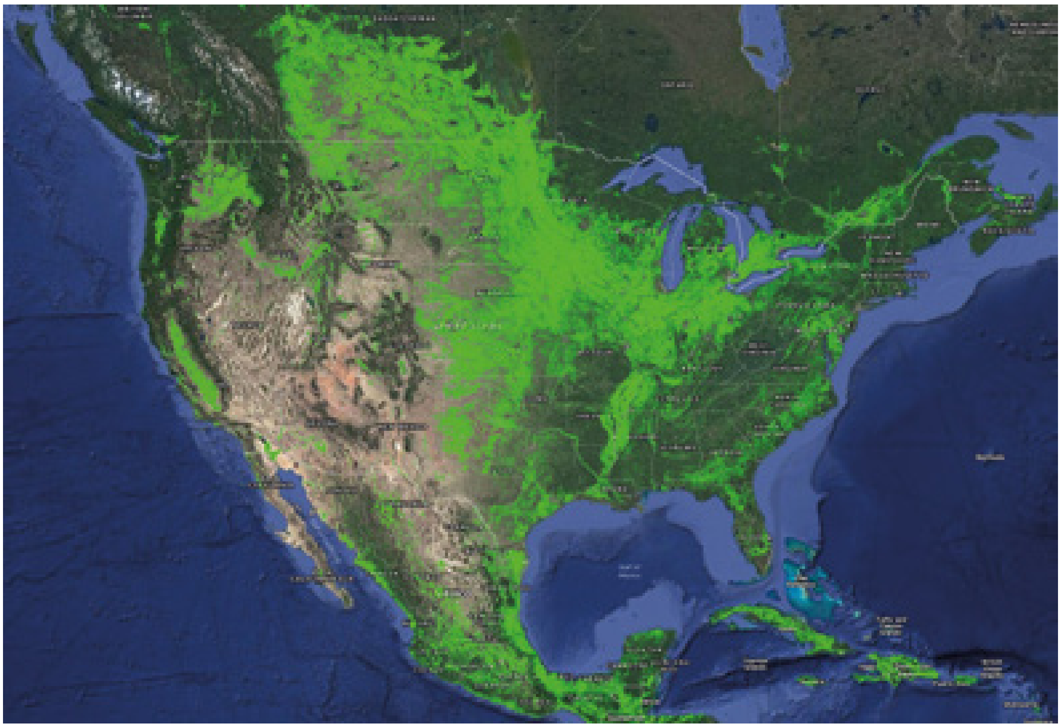

Figure 2- Map of Croplands in the United States

wastewater from homes, businesses, and many industries. However, this is not cost-effective for lowland rural watersheds with low population density. Constructed wetlands within a typical lowland rural watershed in Eastern China had been found to result in a reduction of nitrogen and phosphorus load identical to WWTP. Additionally, it increased macrophyte (aquatic plant) coverage between 10% and 15%, and was found to be under half of the annual cost of WWTP's at 24,012 Yuan per year compared to the 65,538 Yuan per year of WWTPs. Additionally, minimising the use of fertiliser prevents unused fertiliser from being lost via runoff into bodies of water after rainfall.

Atmospheric deposition is where emissions released from the burning of fossil fuels are absorbed by either bodies of water or land. Atmospheric deposition can be mitigated by minimising the reliance of fossil fuels for energy, for example by using more fuel efficient or sustainably powered cars. Cleaning products often contain phosphates which are used to help remove stains, dirt and other contaminants. Washing these down the drain can also contribute to eutrophication.

Furthermore, two stage-ditches and vegetative filter strips could both be used to prevent soil degradation, reducing run-off and ultimately eutrophication. Two stage ditches are designed so that low flows are confined to the main channel, but flood flows stay within the banks of the second stage (Figure 3). A wider ditch with gradual banks would slow the flow of water, creating more stable banks. Vegetation also helps slow the flow of water, further stabilising the banks and allowing sediments to be deposited and allowing vegetation to utilise nutrients deposited with this sediment. Studies have found that two stage ditches accumulate sediment (1-13 mm) over their lifetime, do not require further clean out or maintenance, reduce soluble reactive phosphorus concentrations by over 50%, and turbidity by up to 80%. They also reduce soluble reactive phosphorus concentrations by over 50%.

Additionally, vegetative filter strips, which are a block of vegetation such as grasses, trees or bushes located in the lower level of a field producing sediments and other contaminants along rivers, creeks or ponds, reduced the volume of runoff from 40-100%.

Ultimately, eutrophication is the process of algae blooming due to an influx of nutrients due to human interference, with particularly significant impacts within the Gulf of Mexico, where much of America's farmland runoff flows into. This issue can be addressed through several processes including minimising the reliance of fossil fuels, and the construction of two-stage ditches. However, these interventionist processes can be costly in terms of both time and money. Regardless, these are crucial steps to take, and protecting marine resources and lives starts with mitigating the impacts of eutrophication.

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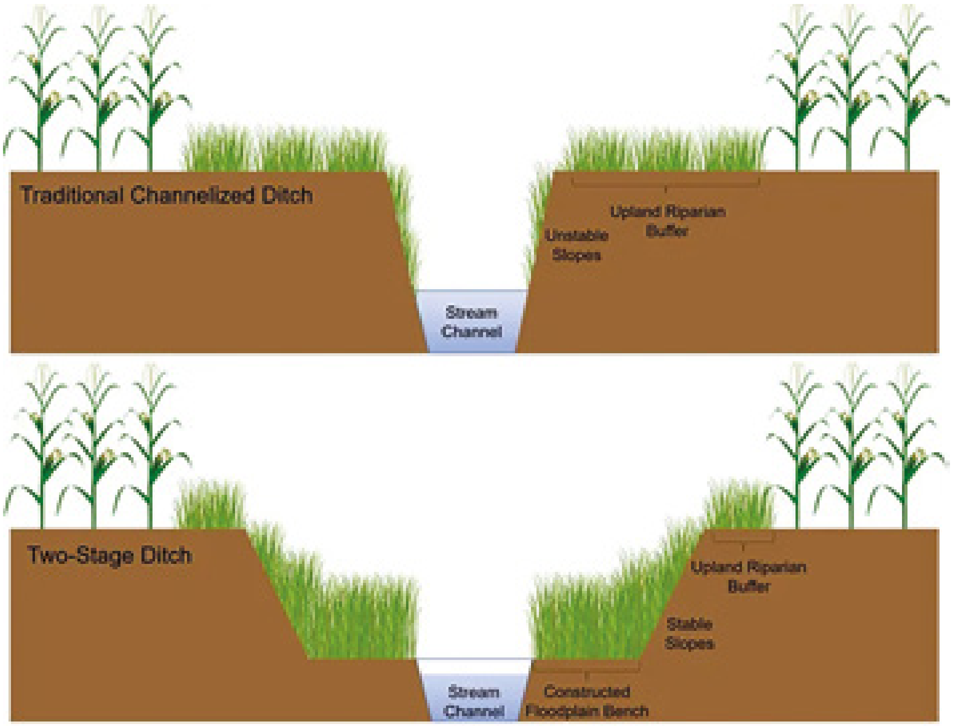

Figure 3- Graphic of a Traditional Channelized Ditch and a Two-Stage Ditch

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Under your skin: The Integumentary System

Words by Devesh Anavkar (Year 9)

Biology

The integumentary system, primarily composed of the skin, is the largest organ in the human body, accounting for about 8% of total body mass. This complex system serves as a protective barrier while performing various vital functions essential for survival and wellbeing.

The skin consists of three main layers: the epidermis, dermis, and hypodermis or subcutaneous tissue (Figure 1). Each layer plays a crucial role in maintaining the skin's overall health and functionality.

The Epidermis

The epidermis is the outermost layer, providing a waterproof barrier and contributing to skin tone. It is primarily composed of keratinocytes, which undergo a process called cornification as they migrate towards the surface. The epidermis also contains melanocytes that produce melanin pigment for UV protection, Langerhans cells that help detect foreign substances, and Merkel cells that act as touch receptors.

The Dermis

Beneath the epidermis lies the dermis, which makes up about 90% of the skin's thickness. This layer contains collagen and elastin fibres for strength and elasticity, blood vessels, lymphatic vessels, hair follicles, sweat glands, and sebaceous glands that produce sebum. Th dermis also houses numerous nerve endings for sensory perception.

The Hypodermis

The deepest layer, the hypodermis or subcutaneous tissue, comprises fat cells (adipocytes) and connective tissue. It insulates the body, acts as an energy reserve, and provides a cushioning effect.

Functions of the Integumentary System

The integumentary system performs several crucial functions. It acts as a protective barrier against pathogens, UV radiation, and mechanical damage. The skin plays a vital role in temperature regulation through sweat production and blood vessel dilation or constriction. It also contains numerous nerve endings for touch, pressure, and temperature perception.

Another important function of the skin is its role in vitamin D synthesis. When exposed to sunlight, the skin produces vitamin D, which is essential for calcium absorption and normal bone metabolism. The integumentary system also contributes to immunity by housing immune cells that help defend against infections.

Skin Appendages

The skin includes several specialised structures known as appendages. Hair follicles produce hair for insulation (Figure 2) and protection, while sebaceous glands secrete sebum to lubricate and waterproof the skin and hair. Sweat glands are crucial for temperature regulation, and nails protect fingertips and enhance fine motor skills.

Maintaining Skin Health

Maintaining skin health is essential for overall wellbeing. To keep your skin healthy, it's important to protect it from excessive sun exposure, stay hydrated, eat a balanced diet rich in vitamins and minerals, use appropriate skincare products, manage stress levels, and get adequate sleep.

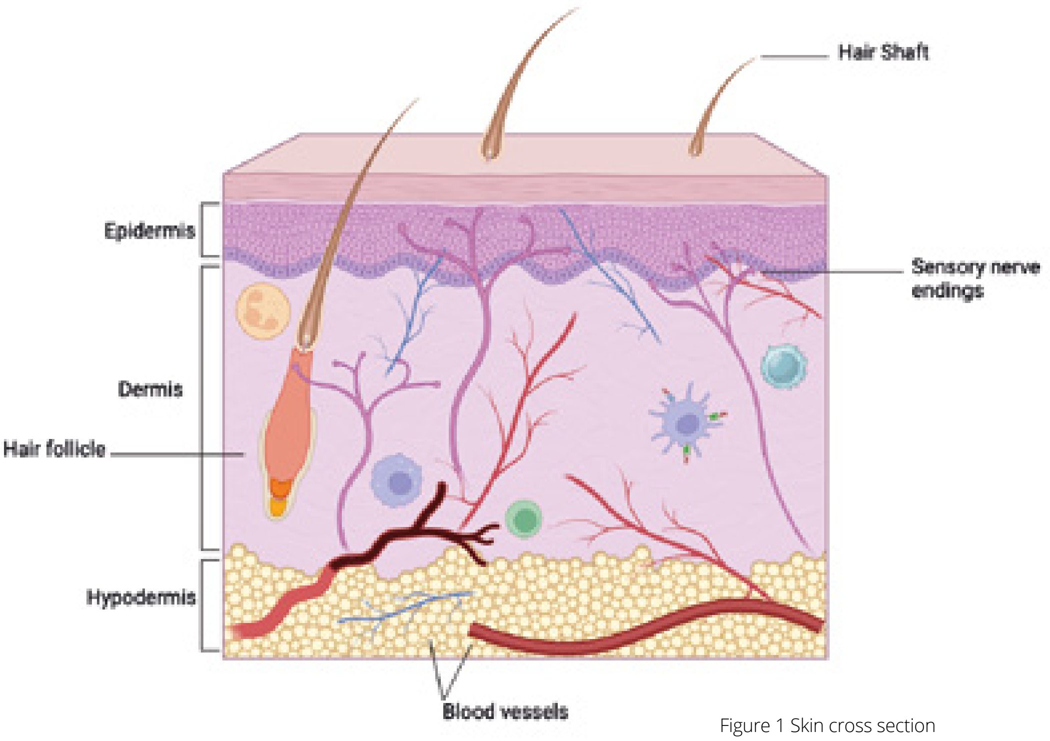

Figure 1 Skin cross section

Figure 2 Raised hair follicles providing an insulative layer

Understanding the structure and functions of the integumentary system is crucial for maintaining overall health and addressing various dermatological conditions. By taking care of our skin, we can ensure that this vital organ continues to protect us effectively while keeping us comfortable in our environment.

The Complexity of Skin

The skin's complexity and importance cannot be overstated. It serves as our first line of defence against external threats while simultaneously regulating our internal environment. From its role in temperature control to its function as a sensory organ, the skin is truly a marvel of biological engineering. By appreciating the intricacies of this remarkable organ, we can better understand how to care for it and maintain its health throughout our lives.

Additional Insights

The integumentary system's complexity extends beyond its primary components. One fascinating aspect is the skin's microbiome, a diverse ecosystem of microorganisms that live on and within the skin. This microbiome plays a crucial role in maintaining skin health, supporting the immune system, and preventing colonisation by harmful pathogens.

The skin's ability to regenerate is another remarkable feature. The epidermis completely renews itself approximately every 28 days, with new cells pushing older ones towards the surface where they eventually shed. This constant renewal process helps maintain the skin's protective properties and allows for healing of minor injuries.

Skin pigmentation, determined by melanin production, is not just about appearance but serves a vital protective function. Melanin acts as a natural sunscreen, absorbing harmful UV radiation and protecting the skin's DNA from damage. The amount and type of melanin produced can vary greatly among individuals, contributing to the wide range of human skin tones.

The skin also plays a role in nonverbal communication. Blushing, pallor, and goosebumps are all visible skin responses that can convey emotional states or physiological conditions. These responses are controlled by the autonomic nervous system and can provide important social cues.

In recent years, research has explored the skin's potential in medical applications. Scientists are investigating ways to use the skin for drug delivery, glucose monitoring for diabetics, and even as a diagnostic tool for various health conditions. These advancements highlight the integumentary system's potential beyond its traditional roles.

Understanding the intricate relationships between the integumentary system and other body systems—such as the nervous, immune, and endocrine systems—continues to be an area of active research. This interconnectedness underscores the skin's importance not just as a barrier but as an integral part of overall health and wellbeing.

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The increasing problem of concussion

Words by Lachlan Logan (Year 8)

Biology

In the past couple of years, concussion has been a big talking point in sport and the health industry. This is because many people have started to see the repercussions and outcomes of multiple concussions, including increased risk of neurodegenerative conditions and memory loss.

Concussion occurs when there is a knock or a blow to the head and the brain moves back and forth rapidly or hits the side of the skull

(Figure 1), this is also known as traumatic brain injury (TMI). The injury alters the speed in which the brain processes and affects other cognitive functions. Concussions are common in contact sports such as AFL, rugby, hockey and boxing but can also happen in activities like motorbike riding and car racing. You can also get concussed by just having a fall or worse, being assaulted. It is important to note that once you have been concussed once, the risk and likeliness of being concussed again increases, leading to further long term brain tissue injuries. As a result of this, many professional athletes have had to step away from their sport because of health reasons.

Concussion can cause many symptoms, ranging from the time of the concussion (short term) to 1-12 days after the incident (long term). These symptoms can also be used to diagnose you for concussion. If you have had a head injury and experience these symptoms, it can indicate if you are suffering a concussion.

One main symptom of concussion is dizziness. Dizziness can be a short term and/or long term symptom and can cause blurred vision, increased sensitivity to light and sound, balance problems and much more. Dizziness can last for a few seconds to several minutes. The system that controls your balance (vestibular system) is made up of areas located in the inner ear and brain *(Figure 2)*. The vestibular system delivers information regarding spatial awareness and motion, and it helps stabilize you when you move. You can undergo and experience dizziness during concussion if this area is injured or stunned as the brain whiplashes inside of your skull. Dizziness can also be caused by headaches and neck injuries that originate from concussion. Another side effect that pairs with dizziness regarding the vestibular system during concussion, is ringing in the ears, given this is where part of the vestibular system is located.

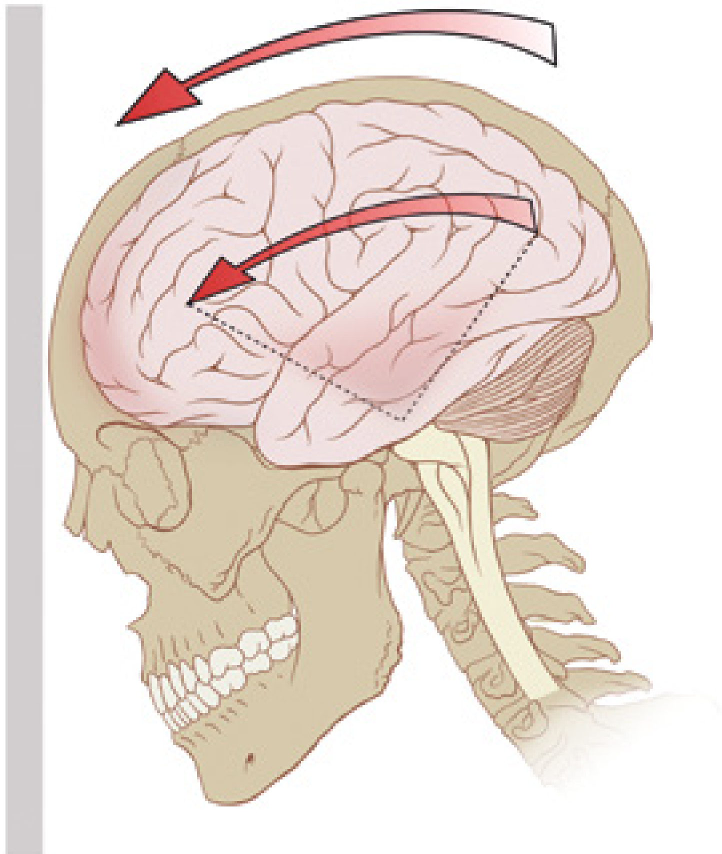

Figure 1 Diagram of what happens during concussion.

Another symptom experienced during concussion is vomiting or nausea, this generally occurs well after you originally get concussed. The feeling of nausea and the act of vomiting are controlled by the same part of the brain. If you have suffered a concussion, these symptoms can indicate that there is increased pressure on the brain and brain stem. The brain is separated into different sections, each with its own function, and some are more sensitive to blows or react differently to others. The nerve centres in your brain that control vomiting and nausea are extremely sensitive to sudden changes in pressure. This means when a sudden jolt occurs, caused by concussion, pressure changes and impact on that sector of the brain can cause nausea and vomiting. Additionally, impacts can disorientate balance centres in the brain that assist the other nerves in controlling vomiting and nausea. It is also important to note that in some very serious circumstances brain bleed can occur from concussion with vomiting and nausea being one of the symptoms.

There are a range of other symptoms doctors use to assist in diagnosing concussion such as fatigue, headaches, concentration problems, ringing in the ears, memory loss, and loss of consciousness at the time of the event. They can also

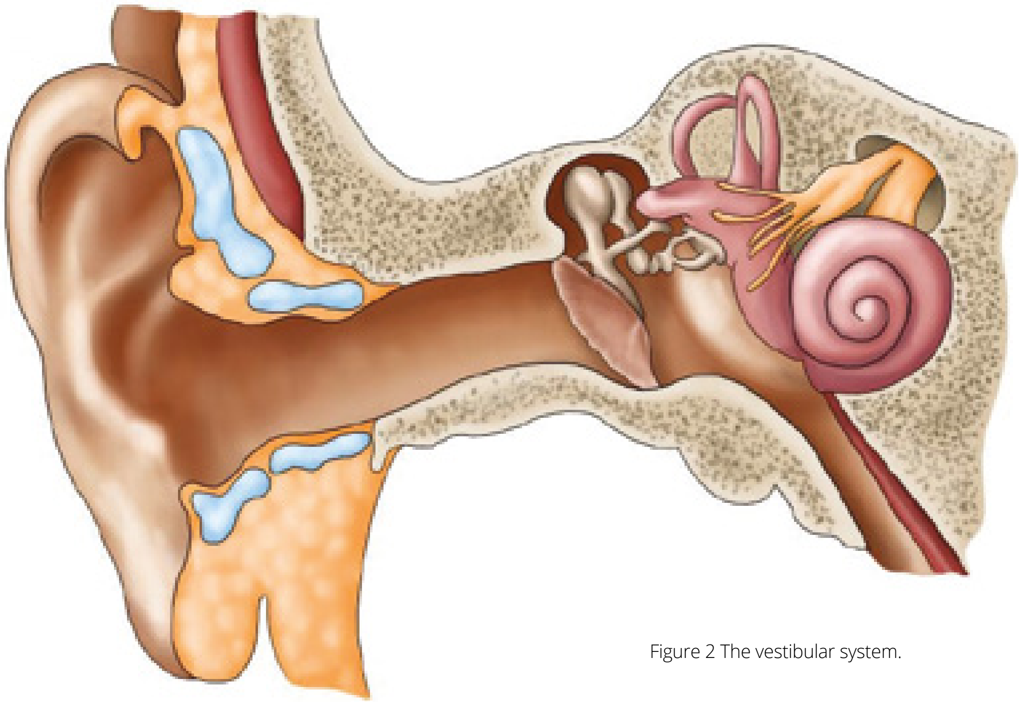

Figure 2 The vestibular system.

test basic brain functions by asking questions and asking for you to complete certain activities.

Scientists have developed technological advancements that can help diagnose concussion more accurately. One of these is a magnetic resonance imaging (MRI) scan. MRI uses a strong magnetic field and radio waves to form a picture of the brain. There is one MRI imaging technique called diffusion imaging which can detect structural changes in the brain by analysing patterns of water movement through brain tissues. This can reveal subtle concussion damage to the brain. Diffusion imaging includes looking at disruptions in white matter, the white cellular framework of the brain. The white matter has microscopic breaks that can affect brain function by not allowing neurons to connect properly.

In conclusion, there are so many ways concussion can be identified from visible symptoms like dizziness and nausea, to modern technology using MRI scans. The human brain is a wonderful gift, and we should look after it, not pushing it to the physical limit and testing it with concussion.

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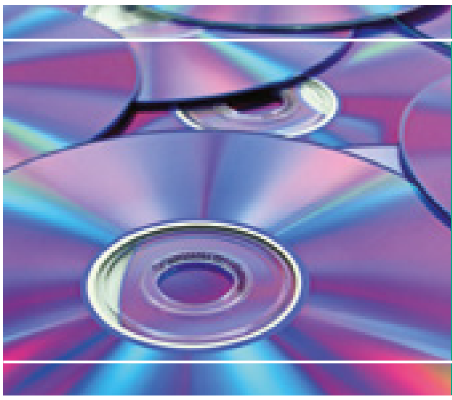

1980s

Compact discs were invented, changing data storage and the music industry forever

Algae-based livestock feed

Words by Louis Kellaway (Year 12)

Biology

Cattle each produce an average of 100kg of methane yearly, contributing significantly to the issue of global warming. The implementation of algae-based feed has been found to reduce these emissions, generally involving the addition of seaweed's bioactive compounds into the feed of livestock as additives or mixed with their drinking water. Agricultural and economic benefits, including improvements in livestock productivity and decreased costs of production are also influencing this increase in algae-based livestock feed. However, while many positive effects result from seaweed's implementation into livestock feed, some limitations such as health, risks, environmental damage from harvesting, legal issues and insufficient global production challenge the innovation.

The natural greenhouse effect, is where the Earth is warmed by the trapping of infra-red radiation (heat) by greenhouse gases in the atmosphere, allowing the Earth to maintain a temperature warm enough to sustain life (Figure 1).

Climate change is a major global issue that involves changes to the Earth's temperature and weather patterns over time. Global warming is an issue with similar side effects, but is specifically the long-term increase of Earth's temperature, which since 1880 has risen by 1.1^{o}C. Increased greenhouse gas emissions add to their concentration in the atmosphere. This causes the Enhanced Greenhouse Effect due to more infrared radiation being trapped near the Earth's surface (Figure 1) leading to global warming. These emissions are generally produced by human activity.

The emission of cows' digestive gas alone makes up 15% of the world's enhanced greenhouse gas emissions, contributing greatly to climate change. Ruminant methane production occurs due to the fermentation of feed in the rumen (the largest component of a ruminant's stomach, utilised for storage). Methanogens, a type of microbe found in the rumen, produce methane from the fermented feed. Certain seaweeds contain different bioactive compounds such as bromoform that can effectively inhibit the methanogens, significantly reducing ruminant methane production. *Asparagopsis armata*, a type of red seaweed found in Tasmania, has become one of the most prolifically used as an additive in livestock feed. It contains bromoform, which allows it to significantly reduce ruminant methane production. Many other seaweed types have also been found to reduce ruminant methane emissions; however, none have been as effective as *A. armata.*

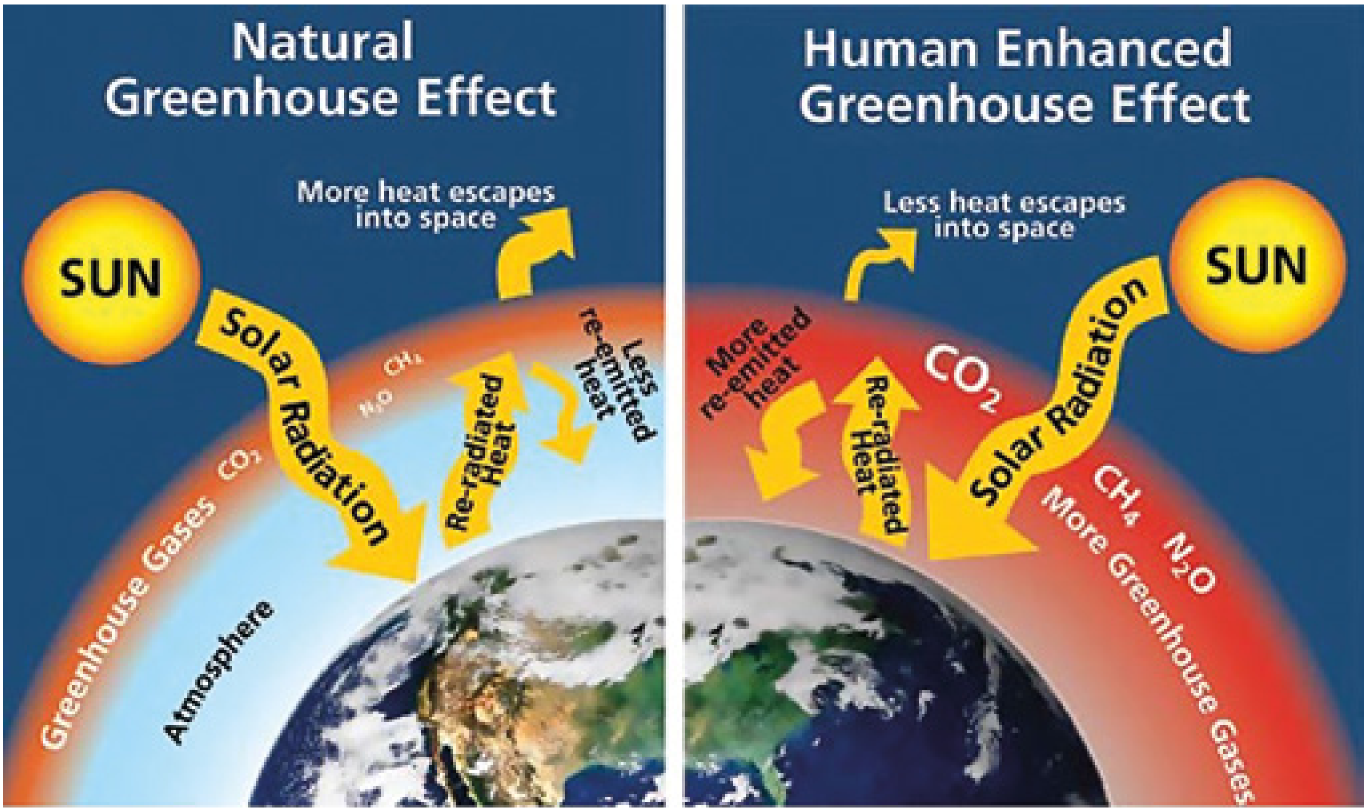

Figure 1: Shows the difference between the natural and enhanced greenhouse effects and the impacts the enhanced greenhouse emissions have upon Earth's atmosphere.

Melting glaciers, increased natural disaster frequency and air pollution are all consequences of global warming, to which the methane emissions of livestock contribute. Melting of glaciers and other ice regions is an issue as it reduces the land availability for the inhabiting wildlife and causes the sea level to rise, which can be hazardous to low-lying coastal areas, and increase flooding. Increased natural disasters would endanger all life on Earth, whilst pollution would pose a similar threat by impacting the lung and heart health of many animals, and also damage plants by reducing sunlight and causing acid rain. Seaweed's ability to inhibit the methane-producing microbes and significantly reduce ruminant methane emissions, promotes the application, considering the gradual deterioration of Earth's climate. FutureFeed is one of the major companies commercialising the use of *Asparagopsis* seaweed in the form of a supplement to reduce ruminant methane production. If a ruminant's diet composition includes 0.2 - 1% of *Asparagopsis* seaweed, studies by different sources have found methane emissions can be reduced in varying amounts between 50% to 98%, showing the large difference a small amount of seaweed can have. It is projected that if just 10% of global ruminant producers adopted FutureFeed as an ingredient to feed their livestock, it would have the same impact for our climate as removing 100 million cars from the world's roads. This information is part of a growing body of research which demonstrates the potential of the impacts of the implementation of seaweed into livestock diets in the quest to slow global warming and reduce its adverse effects on the environment.

A Canadian farmer first noticed consistent performance improvements in his livestock that had access to seaweed from water sources around the property. Further testing was conducted based on this discovery, where it was found that seaweed consumption caused cattle to gain weight using less feed. Similarly, female cows with algae-based diets were able to produce more milk than the ones that did not. Statistically, 23 million additional people could be fed by the improved ruminant productivity if 10% of livestock farmers were to implement seaweed additives into the diet of their cattle.

If livestock with algae-based diets gain weight more quickly, and produce more milk without consuming as much feed, the cost of production for farmers would decrease dramatically if seaweed-based feed can be accessed readily and at a reasonable price. Therefore, algae-based feed could lead to increased farmer profit, with a greater output relative to input. Economically, as more farmers begin to implement the algae-based feed, many opportunities would open in the seaweed production market, allowing for the creation of firms like *Sea Forest,* who specialise in producing *Asparagopsis* seaweed and developing methods to extract and utilise the seaweed's bioactive compounds. The formation of new industries and the creation of jobs would also have a large macroeconomic impact, reducing unemployment and increasing real gross domestic product (GDP), the total output of an economy, in many countries such as Australia.

One of the current limitations is that the full effects of a seaweed diet on livestock and their products are still unknown. Although testing is underway, because it is still a relatively new concept, there is a lot to learn regarding seaweed's impacts. This means it may take time before testing is complete and all countries approve it as an additive. Animal feed additives in the US for example are categorised as animal drugs, which the FDA take seven years on average to approve, while in Australia this is generally not the case. Therefore, lots of time and money may be spent to gain approval and regulate the implementation of seaweed into the diet of livestock in countries like the US. Of the testing conducted so far, it has been found that certain seaweeds contain a high level of iodine. Some of the milk extracted from cows that had consumed seaweed, contained levels of iodine above the limit that is safe for children, which can cause thyroid problems. Worldwide seaweed production is also nowhere near the level it needs to be for global implementation to occur. It is projected that 3.2 million metric tonnes of dry seaweed would need to be produced annually to make up 1% of the diet of all the cattle in the US, while only 32 million metric tonnes were produced globally during 2018. This demonstrates the challenge of producing enough seaweed for the global implementation of algae-based feed considering seaweed is also harvested for other uses including cosmetics, fertilizer and for human consumption. Seaweed farming can also have negative effects, decreasing the amount of sunlight that reaches photosynthetic plants on the seafloor and the equipment utilised in harvesting can also damage the habitat and harm local wildlife.

Due to the large number of positive outcomes that arise from the implementation of seaweed feed, it will likely expand and become globally implemented once the full effects are understood through further testing. One of the positive future impacts of algae-based feed is the decrease in greenhouse gas emissions. The decrease in ruminant methane production would slow down climate change and maintain a higher quality of life for people now and future generations due to the minimisation of negative environmental changes. With improved livestock productivity, more food could be produced utilising fewer resources and less will be exhausted by farming. In addition, enhanced productivity will likely improve the current standard of living, as with increased food availability, it becomes possible to feed more people, tackling the issue of world hunger. Economically, the productivity improvements will also increase the real GDP of countries with large agricultural sectors due to increased animal product production. Countries surrounded by water would have the opportunity to create and/or expand their seaweed harvesting industries, paving the way for new and existing firms. In the long-term, decreases in unemployment towards the ideal percentage of 3.5-4.5% would likely also occur, as more jobs are created in the industries producing mass amounts of seaweed.

Ultimately, there are numerous positive impacts that have and will arise from the implementation of seaweed, whether it be through reducing enhanced greenhouse gas emissions, increasing livestock productivity or helping achieve multiple macroeconomic objectives, the different factors all strongly influence the global implementation of seaweed into the diet of livestock. While some medical and regulatory limitations may occur from the process of passing seaweed as feed, the positive factors outweigh them, particularly considering the significance of global warming and seaweed feed's ability to slow it down.

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Xenotransplantation advancements open new opportunity to alleviate worldwide organ shortage

Words by Noah Thiessen (Year 12)

Biology

Australia currently has over 264,000 people living with kidney failure. Over 1,800 of those are awaiting a kidney transplant, and an additional 14,000 are undergoing dialysis. In a field where the demand for transplant organs significantly outweighs the supply, scientists are experimenting with xenotransplantation to increase the supply of kidney transplants. Xenotransplantation is any procedure that involves the transplantation, implantation of non-human cells, tissues or organs into human recipients to treat medical conditions.

The undersupply of kidneys for transplant has had significant social and emotional impacts on individuals awaiting a transplant, as well as their families. With more than 50 people dying each day in Australia from causes related to Chronic Kidney Disease (CKD), the loss of life is extreme. This has a profound impact on close friends and family, and the wider community. The kidney crisis has deprived thousands of patients of an improved quality of life. Moreover, dialysis treatment has a large impact on the mental health of patients due to its financial burden and time commitment. An Australian study found that 41% of patients undergoing dialysis treatment have significant depressive symptoms, compared to 18% of people in the overall Australian population. As mental health is a key component of overall health and well-being, the stresses associated with dialysis treatment result in reduced quality of life in patients.

For many patients, treatment for CKD involves dialysis which involves large economic costs. For individuals living with Stage 5 CKD, costs exceed $182,000 primarily due to unproductive treatment therapies. Across Australia, there has been close to a 100% increase in patients requiring dialysis between 2008 and 2020. In 2023, Australians lost an estimated 63,400 years of healthy life due to CKD. This accounted for 1.1% of the total burden of disease in Australia which is measured of the years of healthy life lost from living with illness or dying prematurely. Moreover, the economic impact of CKD was estimated to be 9.9 billion AUD in 2021. Of this amount, over 50% was due to lost productivity costs involving reduced employment and increased absenteeism, 24% was due to healthcare system costs and 24% was attributed to other financial costs. These costs impact not only individuals but also employers and the federal government to an extent of approximately $2 billion per group.

Ultimately, due to these significant economic impacts and psychological effects of dialysis, scientists are motivated to explore alternative avenues to attain kidneys for transplant to address the severe shortage. Xenotransplantation is considered an accepted avenue for expansion due to the potential for positive advances to be made in the field.

Currently, xenotransplantation is an experimental treatment and is only permitted for use in extreme cases. An undersupply of available human organs for transplant has led to increased research into the study of xenotransplantation in the hope that animal organs can be used to transplant into humans. The most promising source of organs that can be used for xenotransplantation are pig kidneys, given their similar size to humans, wide spread availability, and low risk of transferring diseases. During March of 2024, the first pig kidney was transplanted into a human recipient through the aid of gene-editing and modification. This was achieved using genome editing technology involving Clustered Regularly Interspaced Short Palindromic Repeats (CRISPR). CRISPR is a natural component of bacterial immune systems, that protects against viruses. When infected, the bacteria store a copy of viral DNA that allows it to remember the virus. If it becomes reinfected by the same virus, a guide RNA molecule consisting of a short sequence of ribonucleic acid and a Cas9 enzyme are used to combat the virus. Cas9 enzymes are produced by the CRISPR system and cuts DNA at specific locations allowing for genes to be added or removed at these sites. These enzymes work in conjunction with guide RNA molecules - short RNA sequences that are synthetically made to be complementary to a specific section of DNA. They bind to the DNA and 'guide' the Cas9 to this location where it acts as a pair of molecular scissors and cuts DNA this location. This system is now used to edit genomes and in this instance was applied to the field of xenotransplantation.

The xenotransplant was undertaken by Harvard Medical School scientists who used the CRISPR system to make 69 genomic edits to the pig kidney, to adequately prepare it for transplant. These edits were made to remove pig genes that the human immune system reacts to, inactivate viruses in all pig genomes, and add certain human genes to improve the compatibility of the kidney for the human recipient. Once transplanted, the kidney immediately produced urine, indicating a successful transplant. Unfortunately, the man to whom the pig kidney was successfully transplanted into passed away soon after, however was able to live almost two months, much of which was out of hospital. This led to cautious optimism for this procedure for the future. However, clearly, numerous risks are still associated in its early development stages.

The concept of xenotransplantation is not new, but previous attempts have been highly unsuccessful due to organ rejection in participants. The development of CRISPR has opened new pathways, as genetic modification can reduce, or potentially eliminate organ rejection in humans. However, despite the revolution of CRISPR editing, the rejection in humans of pig kidneys which have undergone xenotransplantation remains an issue. Although the first recipient did not immediately reject the pig kidney, there is no prior evidence that suggested that the organ would survive more than seven months, and he ended up passing away before then to causes unrelated to the transplant. Pigs carry viruses such as herpes viruses which have severe zoonotic potential. Despite the use of CRISPR for gene editing, these viruses remain a high risk for xenotransplantation outcomes. These risks have been exemplified in the global pandemic COVID-19, which most likely began from zoonotic infections. Therefore, for clinical trials to continue, participants must be aware of the health risks associated with having a pig organ and all its potential viruses transplanted into their body.

There are also significant ethical issues surrounding xenotransplantation. Pigs used for kidney transplants have considerably different lives to pigs farmed for meat and their welfare must be considered. These pigs must be farmed without contact with other animals, using infection control measures to minimise the potential for viruses. Moreover, they are required to undergo frequent blood and tissue sampling, and potentially repeated surgeries to utilise their organs and tissues for transplants. As pigs are highly intelligent and social animals exposing them to repeated pain and distress, this could be viewed to be ethically wrong. Additionally, cultural groups such as Muslims and Jews associate pork as a food taboo, and therefore would not accept the use of pig organs for xenotransplantation. These health and ethical issues associated with xenotransplantation could reduce its acceptance in society.

Despite ethical and health concerns, the potential for success in xenotransplantation incentivises further scientific research. Data shows that a 30-year-old patient undergoing dialysis has a life expectancy of 15 years, whereas if they receive a live kidney transplant this figure rises to 40 years. Therefore, by increasing the availability of kidneys, individuals experiencing CKD will have the potential for longer lives.

Although there is only limited data showing that xenotransplantation of kidneys will result in longer life spans than dialysis treatment, the potential for this to be the case encourages further research. Additionally, advances will reduce waitlist mortality for critically ill patients of CKD. The long-term goal for xenotransplantation is to save millions of lives. The cost of the initial trials has been substantial, but if the surgery was to become routine, that cost should diminish due to the economies of scale. It is estimated that if procedures become more efficient and cost-effective, xenotransplantation can mitigate the economic burden of dialysis. Based on cost projections of $166,000 AUD for xenotransplants of kidneys, two years of survival in patients would result in a more cost-effective procedure than dialysis. Thus, there is an economic incentive to pursue xenotransplantation.

The success of the first-ever live xenotransplantation of a pig kidney to a human recipient using CRISPR Cas9 editing creates newfound hope that the worldwide organ shortage can be resolved through xenotransplantation. Ethical concerns and health issues stand as barriers to progression, but the demand to obtain viable kidneys outweighs these concerns and accentuates the need for scientific development in the field of xenotransplantation.

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Sustainable aviation fuel as an alternative to traditional jet fuel to reduce carbon dioxide emissions

Words by Aryan Madan (Year 12)

Chemistry

Many of the world's population look to air travel as a method of long-distance travel. However, what most people do not think about when flying is the significant carbon emissions being released into the atmosphere. Today, aviation accounts for 2.5% of global carbon dioxide (CO_2) emissions and has already contributed to approximately 4% of global warming to date. Currently, planes are fuelled by traditional petroleum-based fuels, with almost all jet fuel being derived from crude oil refineries, leading to extensive use of non-renewable resources, resulting in high amounts of greenhouse gas emissions. However, in recent years, Sustainable Aviation Fuel (SAF) has been a crucial development in the fight to reduce CO_2 emissions from aviation. This report will explore how SAF is as an alternative to current jet fuel.

SAF is a type of biofuel, meaning it is derived from recently living plant or animal materials rather than fossil fuels, and has the potential to reduce aviation greenhouse gas emissions by 80% compared with traditional jet fuel. Currently there are many different methods to produce suitable and safe SAF, however strict sustainability requirements of a 50% greenhouse gas emission reduction compared to traditional petroleum-based jet fuel is a mandatory target for producers. Generally, there are two ways to produce SAF; converting sustainable feedstocks into synthetic kerosene (SK), which is then blended with conventional jet fuel to produce SAF. The second method involves producing SAF through co-processing, where up to 5% of sustainable feedstocks are processed alongside fossil feedstocks through hydro-processing in the refinery. The most widely used production method is Hydro processed Esters and Fatty Acids (HEFA) which is a part of the SK technology pathway. HEFA involves refining vegetable oils, animal fats or used cooking oil into a mixture of hydrocarbons that can be blended with traditional jet fuel.

This process involves three main steps, as depicted in Figure 1: pre-treatment, hydrotreating and hydro isomerisation. Feedstocks such as vegetable oils and animal fats may contain impurities and contaminants and therefore these must be filtered out during the pre-treatment stage to increase

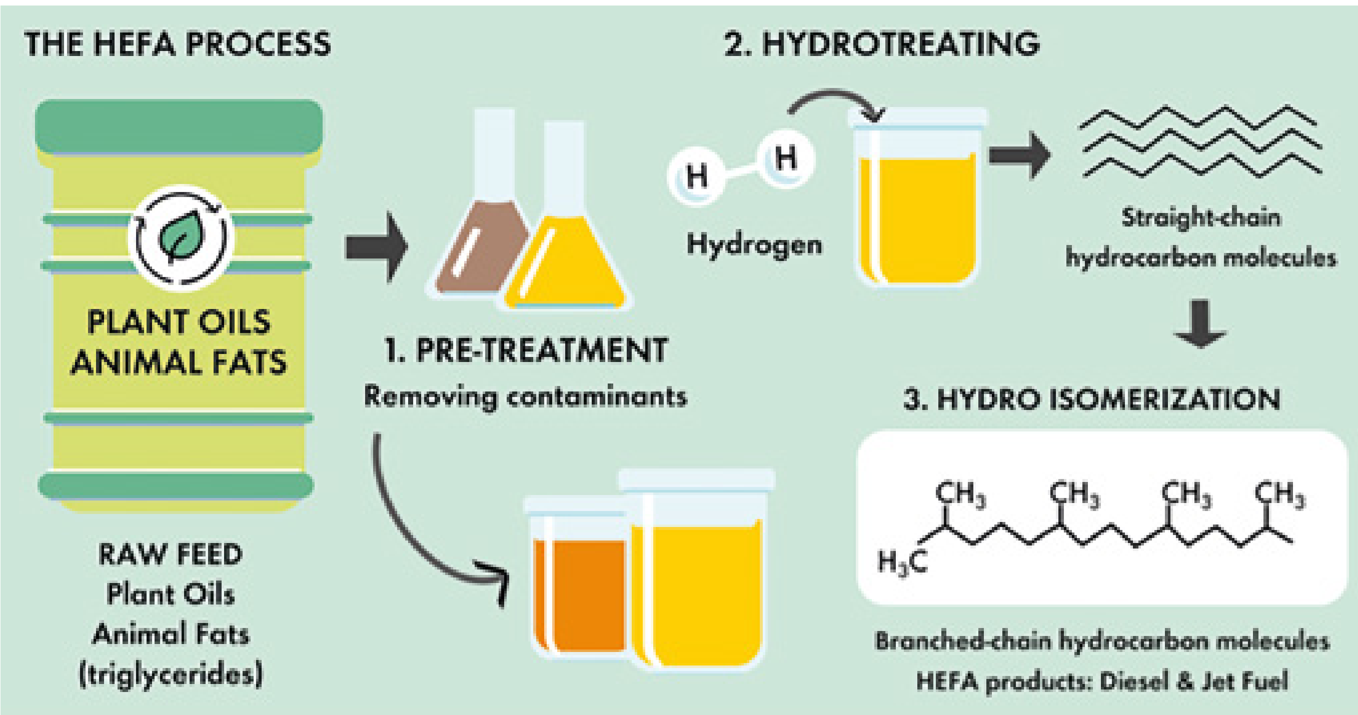

Figure 1 The HEFA process

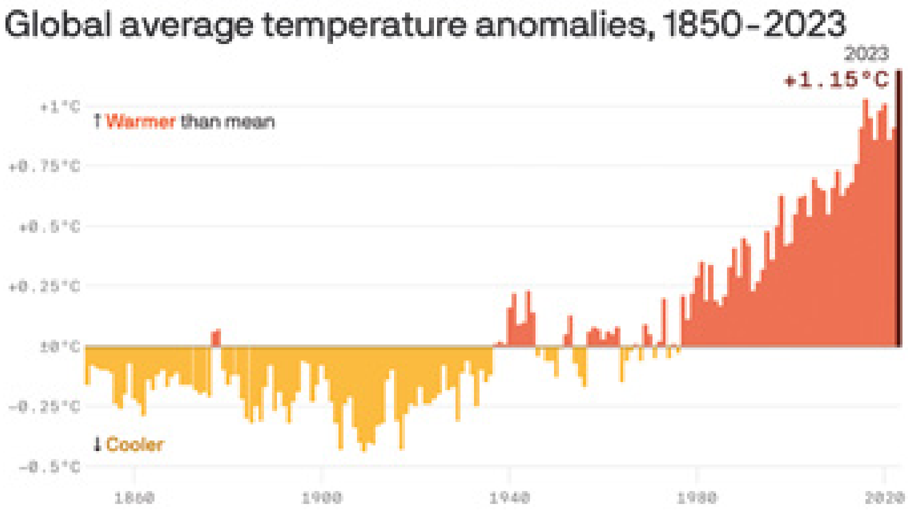

Figure 2 Global temperature rise 1850-2023

feedstock quality. The purified feedstock then undergoes hydrogenation under high temperature and with the presence of catalyst, saturating the hydrocarbon chains to result in straight-chain hydrocarbon molecules. Finally, these hydrocarbons undergo hydro isomerisation with the presence of a catalyst whereby the straight chained hydrocarbons are converted into isomers containing methyl side chains, resulting in SAF. As mentioned previously, the HEFA pathway places heavy reliance on catalysts, specifically a heterogeneous catalytic system involving effective production rates and resource usage for a sustainable process. While the majority of planes using SAF use fuel produced by the HEFA pathway, limited feedstock availability means it is expected that other SAF production methods will be explored and ultimately increased.

Following the rise in global temperature over many years as seen in Figure 2, the United Nations has called for carbon dioxide emissions to reach net zero by 2050. The establishment of this regulation along with the societal consensus of urgent environmental improvements has prompted and influenced the aviation industry to reduce carbon emissions from aircraft through the use of SAF, with current estimates demonstrating that SAF could contribute around 65% of the emission reduction needed by the aviation industry to reach net-zero in 2050. Reducing carbon emissions from aircraft will decrease atmospheric carbon dioxide and hence the effects of global warming will also reduce, having positive environmental impacts and contributing to societal efforts in combatting this global issue.

Over the years, the economic effect of global warming has changed with government spending increasing in the wake of the flow on effect of rapid climate change causing natural disasters such as bushfires, cyclones and flooding, all of which are common in Australia. Hence, the Australian government has pledged to invest $24.9 billion dollars over the next 6 years to deliver on climate change and energy transformations. This significant economic commitment by the government demonstrates the severity of the effects of climate change, with aviation already contributing to 4% of global warming to date. The development of sustainable fuels such as SAF aims to decrease the burdens of climate change and reduce the spendings committed by the government in the long run to address climate change induced natural disasters. Overall, the use of SAF will reduce economical stress due to climate change and in turn allow those funds to be allocated elsewhere for a more sustainable economic situation for the government. Hence, the development of new fuel products such as SAF in the light of economic influence from the government, highlights how increasing the number of planes utilising SAF will contribute positively to the economy as well as potentially increasing the number of jobs in the industry as demand for SAF rises, while also contributing to societies mission of net zero by 2050.

With current jet fuel being derived from non-renewable sources and contributing heavily to climate change, the industry has had to increase SAF production. In 2023 SAF volumes reached over 600 million litres, double the 300 million litres produced in 2022, signifying the progression in SAF production and the environmental benefits to come. The application of SAF as a new sustainable fuel technology in the aviation industry will not only decrease carbon emissions, but also provide new opportunities to farmers as they are able to sell their biowaste to SAF producers rather than letting it be transported to landfills, having both positive economic and environmental implications. Moreover, the advancements and science behind SAF technology will not only benefit the aviation industry but may also be applied to other industries such as renewable fuels for cars such as biodiesel.

Although many benefits have arisen following the increase in SAF production, there are also limitations with this new fuel. Currently, although SAF has proven to significantly reduce carbon emissions from aircraft, extremely high production and purchase costs limits SAF's widespread use in the aviation industry, with airfares potentially increasing to offset SAF's high price point. Despite this, the industry expects SAF to become more financially viable as demand for SAF grows and technology advances. In addition, access to SAF itself presents a problem to potential customers and users. As SAF is a relatively new fuel source, the distribution, and refuelling of SAF is not yet widespread. SAF would also need to be transported on road, hence transit vehicles will emit large volumes of greenhouse gas emissions, and as such, advancing the technology of biofuels for road transportation with the aid of SAF will ultimately be needed. Therefore, in order for SAF to become more prominent in the aviation industry, scientists and researchers must find a solution to increase its economic and environmental viability.

While SAF has already shown to be a suitable alternative to non-renewable aviation fuels, further development is necessary in order for SAF to become a permanent staple within this industry. Although SAF development is currently limited for a number of reasons, countries such as Australia have devised plans to scale production and integrate SAF in the coming years. The CSIRO have formed the SAF roadmap which entails the pathway for Australian aviation to reach net zero by 2050. The study suggests that there is enough feedstock to supply almost five billion litres of SAF production in Australia in 2025 and up to 14 billion litres by 2050, with Australia currently using approximately 10 billion litres of petroleum-based jet fuel. As such, current production and refining capabilities must advance for supply to meet demand. Also noted in the CSIRO roadmap were two cost-efficient production pathways for SAF. The first is the biogenic (produced by living organisms) pathway which is the current method of production providing the most economically viable path in the short to medium term. However, in the longer term where there are many SAF-producing companies, risks of cost increase for feedstock may occur as well as reaching a natural supply limit. The second proposed pathway is the power to liquid pathway (PtL) where renewable energy such as hydrogen is converted into liquid fuels. The PtL pathway begins with a greater price premium than biogenic methods but falls as the hydrogen economy grows and as such is seen as a potential pathway to reduce SAF production costs. In this way, research and advancements in technology will further offer intrinsic interest within SAF production. Finally, there is no doubt that in the coming years, SAF will not only benefit the environment by reducing carbon dioxide emissions but will also boost the economy of many countries as poorer nations with an abundance of biowaste from agriculture are able to have another source of income.

Overall, SAF is poised to be a suitable alternative to traditional aviation fuels in the future, with results already demonstrating SAF's ability to significantly reduce emissions from aircraft. The growing threat of climate change caused by global warming has influenced the industry to look to further develop SAF in order to reap the environmental benefits. Furthermore, expanding and applying the SAF technology will see many people and in particular airlines gain economic reward with increased production and consumption. However, there are currently limitations with SAF, with significant costs required to produce and provide SAF, requiring the industry to further develop the technology to allow it to become more widespread and the new standard of aviation fuel in the future.

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Graphite and lithium-ion battery technology

Words by Hugh Willcox (Year 11)

Chemistry

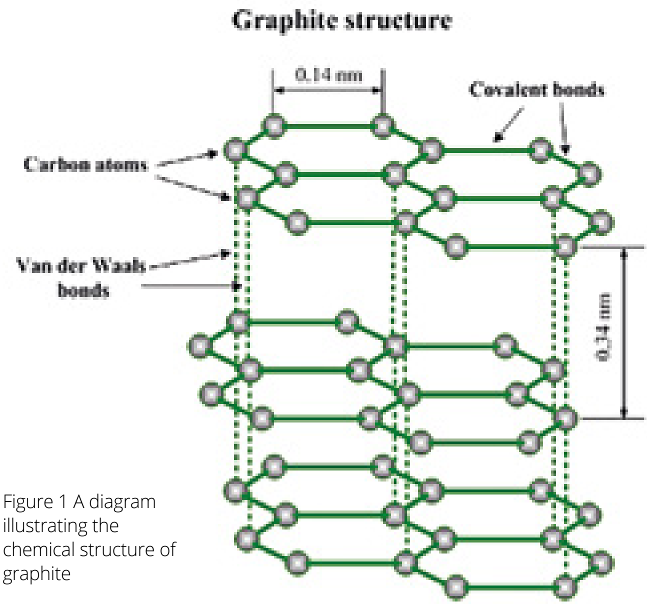

Figure 1 A diagram illustrating the chemical structure of graphite

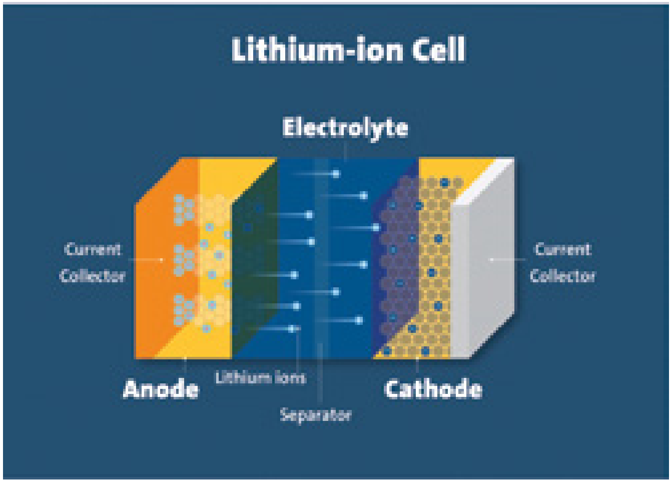

Figure 2 A diagram illustrating the chemical structure of a lithium-ion battery:

With the worlds carbon dioxide emissions exceeding 40 billion tons in 2023, it is for justifiable reason that the world needs to transition to more sustainable forms of energy storage to mitigate the ongoing problems of greenhouse gas emissions and subsequent climate change. The lithium-ion battery therefore emerges as a sustainable option to revolutionise the energy landscape with its superior cycle life, energy density, and versatility to its counterparts. Consequently, as the demand for lithium-ion batteries increases, graphite has also been widely used as an extremely effective way to produce them.

Graphite is one of carbons three naturally occurring allotropes. More specifically, it is a form of crystalline carbon, that consists of carbon atoms arranged in a distinct hexagonal lattice bonded by strong covalent bonds, with its layers being bonded by weak Van der Waal bonds (Figure 1). Within each carbon atom, there are delocalised electrons, contributing to graphite's high electrical conductivity as electrons move freely throughout the material carrying an electrical charge. This is fundamental for graphite's application in lithium-ion batteries as it can conduct electricity quickly, decreasing for instance, the time the battery takes to charge.

Lithium-ion batteries usually consist of a positive electrode (cathode) made of a lithium metal oxide, a negative electrode (anode) made of typically graphite, an electrolyte solution, and a separator (Figure 2).

When charging, the cathode accepts electrons from an external circuit, causing a reduction reaction to take place where lithium-ions in the form of the cation Li^{+}, are extracted from the lithium metal oxide. These lithium-ions then move towards the anode due to the electrical potential difference between the electrodes, facilitated by the electrolyte solution and pores of the separator. At the anode lithium-ions and the graphite material then undergo an oxidation and reduction reaction respectively, where lithium-ions then intercalate and become stored between the interstitial spaces of graphite's hexagonal lattice structure (Figure 3). Lastly, during the discharging of a lithium-ion battery, this process is reversed, ending with the lithium-ions instead being reinserted into the lattice structure of the lithium metal oxide at the cathode, releasing electrons that power the external circuit during the process (Figure 3)

The widespread use of graphite in lithium-ion batteries has been due to the improvements the material has made for necessary safety standards. Many early prototypes of feasible lithium-ion batteries were consequently abandoned due to safety issues, such as NASA's 1965 lithium-ion battery (the the CuF_2/Li battery), that used lithium metal as the primary anode material. This prototype however was quickly discontinued due to safety concerns as lithium metal was seen to be too unstable with its tendency to form dendrites that led to short circuiting and fires. As a response to these initial failures, many scientists looked into developing a safer anode material, to which Japanese chemist Akira Yoshino in the late 1980s successfully constructed the first prototype of the modern lithium-ion battery. Yoshino added a soft form of graphite as the anode material, with its crystalline structure intercalating one lithium atom for every six carbon atoms in an ordered array between its layers. This use of graphite was revolutionary as it stored lithium-ions for the first time ever in a stable way. This meant that lithium-ion batteries were now considered safe enough for consumers. Consequently by 1991, Sony Corporation through the influence of Yoshino's prototype commercialised the world's first rechargeable lithium-ion battery in its camera the CCD-TR91. Following the success of this launch many other electronic companies also looked to

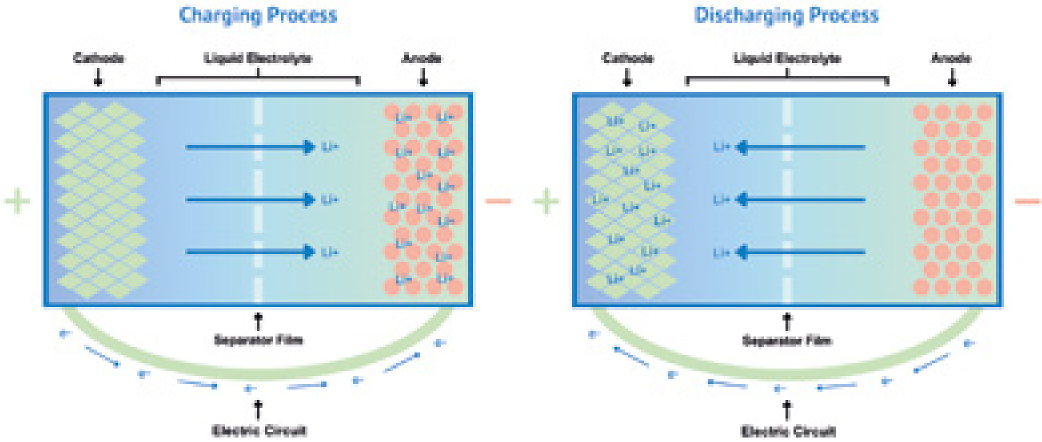

Figure 3 Diagrams representing the charging and discharging process of the lithium-ion battery

make this transition, leading to its commercialisation. Now almost all smartphone companies now using a similar graphite-based lithium-ion battery as the essential component for not only recharging their devices but also ensuring that devices are safe enough for consumers to handle.

Furthermore, the application of graphite in lithium-ion batteries has resulted from the improvements the material has made to the batteries performance capabilities. This is because scientists have measured notable increases in lithium-ion battery energy density when graphite is used as the anode material, thus allowing the batteries to store larger quantities of energy per unit of mass. This is due to graphite having a high theoretical capacity of 372$mAhg^{-1}$ compared to other practical anode materials such as lithium titanate ($Li_4Ti_5O_{12}$), titanium dioxide (TiO_2), and vanadium oxide (V_2O_5), all containing lower theoretical capacities of 175$mAhg^{-1}$, 168$mAhg^{-1}$, and 294$mAhg^{-1}$ respectively.

Additionally, graphite's application has also stemmed from the improvements it has made to lithium-ion batteries capacity retentions, through its ability to remain structurally stable during charging and discharging processes, hence reducing the battery's degradation over time. This includes scientists measuring capacity retentions of the lithium graphite half-cell to maintain a capacity of almost 100% after 35 recharge cycles at room temperature. These significant performance improvements due to graphite's application have most notably impacted automotive based lithium-ion battery demand, which increased by 65% worldwide in 2022 due to the graphite-based lithium-ion battery's ability to meet the rigorous demands of powering electric vehicles effectively. Electric vehicles are now increasingly relying on lithium-ion batteries, because of their competitive physical properties facilitated by graphite application, a trend which is expected to possibly intensify with the growing reliance on electric vehicles in the future. Hence it is evident, that the application of graphite in lithium-ion batteries has been yielded by the improvements the material has made to the physical properties of the battery improving its performance capabilities. This further allowing the use of the lithium-ion batteries in energy demanding tasks such as powering electric vehicles.

In conclusion, it is evident that the use of the material graphite in lithium-ion battery technology has been influenced by the improvements the material has made to necessary safety standards due to its favourable chemical structure. Additionally, graphite's application in lithium-ion batteries has also resulted from the significant improvements the material makes to the batteries physical properties and thus performance capabilities. This has led to the commercialisation of the lithium-ion battery for consumers and use of it in energy demanding tasks such as powering electric vehicles. The widespread adoption of graphite in lithium-ion batteries could possibly allow a new era of sustainable energy storage reducing the worlds greenhouse gas emissions, mitigating climate change in the process.

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Could perovskite replace silicon in future solar cells?

Words by Jesse Rothgrew (Year 12)

Chemistry

Solar energy is the most abundant energy source, with over 170,000 terawatts of solar energy striking Earth every second, over 10,000 times the amount of power the planet uses. Conversely, solar energy comprises only 2% of the world's energy production, suggesting that innovations in solar technology, such as the use of perovskite solar cells, have the potential to make solar energy a more prominent energy source in the future.

Perovskite is a natural mineral composed of calcium titanate (CaTiO3) and has been trialled as a replacement semiconductor for silicon in solar cells. Each cell contains 60 to 72 photovoltaic cells, which transform light energy (from the sun) into electricity to be used or transported as required. In silicon cells, there are two types of semiconductors, 'p-type' and 'n-type'. In both types, the silicon atoms connect to each other to form a crystal lattice, however, each type has different elements added to its lattice to generate a positive charge (electron vacancy) in 'p-type', and a negative charge (electron surplus) in 'n-type'.

As shown in Figure 1, the two types sit adjacent to each other, causing the formation of a 'depletion zone' where they meet, in which the electrons switch positions. When sunlight hits the cell's depletion zone, the electrons in the silicon are ejected, which, provided there is a metallic wire connecting the p-type and n-type layers together, causes the electrons to move from the n-type layer to the p-type layer, generating electricity. In perovskite cells, the silicon semi-conductors are replaced with perovskite, but still rely on the same principles of depleted zones and electron ejection to generate electricity; however, they are much better at absorbing light, have a higher tolerance for defects impurities and imperfections, and can use regions of the solar spectrum largely inaccessible to silicon cells as shown below in Figure 2.

Furthermore, silicon cells have a theoretical limit of 29% efficiency, however, perovskite cells currently have a 34% efficiency, which is expected to increase with further research. The individual strengths of both perovskite and silicon cells led to the creation of a tandem perovskite-silicon solar cell. As shown in Figure 2, perovskite absorbs the shorter wavelengths of light, and silicon absorbs the longer wavelengths of light. This tandem cell is thought to have a theoretical efficiency of up to 45%, over double the efficiency of most silicon cells.

A large amount of energy is required to produce silicon cells. A different material was needed, which led to the development of the perovskite cell. Solar cells create renewable energy; however, silicon cells require a significant amount of energy for their production phase; releasing over five times more carbon dioxide than perovskite cells. This difference in energy input is caused by two key factors: the amount of each element required, and the temperatures required for production. Firstly, perovskite cells use a 0.5-micrometre layer of perovskite, whereas silicon cells use a 200-micrometre layer of silicon, meaning that less material is used per cell, and therefore less energy is consumed during the mining processes. Secondly, for solar cells to function optimally, they require a silicon purity of over 99.99%. The purifying process is extremely energy intensive, including, the reduction of the silica in an electrode arc furnace at 1500-2000°C. In contrast, because perovskite cells can function with significantly lower purities, they only require temperatures of 150°C to reach their required purity, reducing the amount of energy required and therefore the carbon dioxide emissions. This decrease in energy required during production is reflected in the

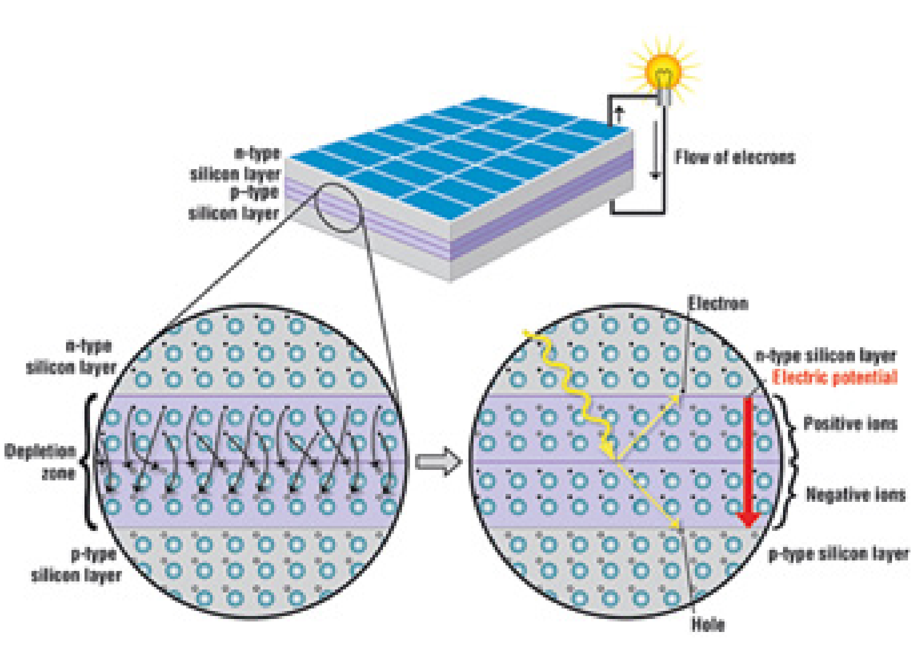

Figure 1: Diagram of the setup for a silicon solar cell, showing the positioning of the n-type and p-type layers

perovskite's 'energy payback time' (the amount of time it takes the cell to produce the energy it took to produce, which is just four months, compared to silicon cells one to three years.

As discussed previously, perovskite's cells have a higher efficiency ceiling than silicon cells, however, this is not their most transformative property. Rather, perovskite cells are thinner, lighter, and more flexible than silicon cells, leading to several new potential applications for solar cells. For example, perovskite cells can be printed on plastic, rather than glass, allowing smaller, foldable cells to be produced, facilitating their use in previously impractical scenarios. For instance, the CSIRO suggests that their lightweight and foldable design could allow them to be used by defence and emergency personnel, especially in rural and remote areas where energy cannot be easily accessed from the electricity grid. Furthermore, their lightweight design and increased efficiency may allow them to be used on planes, cars and drones. Unfortunately, cars and planes have a high weight to surface area ratio, meaning that the cell cannot provide enough energy to fully supply the plane or car, however, it can be used to supplement the required energy. In contrast, ultra-lightweight drones offer a low weight to surface area ratio, with researchers at Johannes Kepler University having successfully attached perovskite solar cells to a drone which significantly extended its flight time. Whilst the drone was not fully self-sufficient, the perovskite cell was only operating at 20% efficiency, suggesting that, if the theoretical limit of 45% was to be reached, perovskite cells might be able to power self-sufficient drones, with potential applications in military and rescue operations.

Whilst there are many applications of perovskite cells, they also face several limitations, including concerns about their stability, long-term use, and toxic materials in their production. For example, due to their comparatively smaller size, perovskite cells are more unreliable when exposed to heat or applied voltage for extended periods of time, both of which are common occurrences for solar cells. Whilst this is a significant challenge, there are already solutions being trialled, specifically with different methods of encapsulating the cell, which is thought to decrease perovskites degradation tendencies. In addition, the lifespan of perovskite cells remains unknown, and even though a cell predicted to last thirty years (the industry standard) has now been developed, it has yet to be trialled, generating doubt in the product which decreases its commercial viability. This is a significant impediment to their development, however, investments by governments could allow the technology to still progress despite its potential flaws. Furthermore, perovskite cells contain a small amount of lead, which, when it rains, can leak out and into the soil, posing a significant danger to wildlife and humans in the area. In response to this threat several strategies to prevent the leaking are being investigated, including lead-free alternatives. Therefore, whilst there are still underlying limitations to the perovskite cells, ongoing research and development is currently being aimed at resolving these issues.

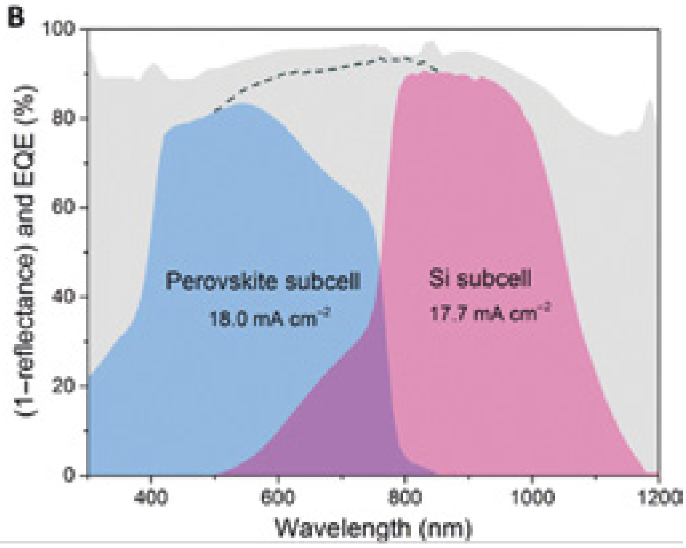

Figure 2: Graph to compare the wavelengths of light absorbed by perovskite and silicon solar cells

As discussed above, there are many current and new applications of perovskite cells. As shown in Figure 3, NASA recently led the first trial of perovskite cells in space, concluding that, despite its thinner, lighter, and more flexible design (compared to silicon cells), it was able to simultaneously withstand space's extreme temperatures, radiation, and light stressors.

Interestingly, the temperature swings the perovskite cell experienced during orbit shrank and expanded the sample, putting stress on it and changing how it interacted with light. However, once back on Earth and bathed in light, its sunlight-absorbing qualities were restored. When discussing the potential of a base on Mars, NASA suggested that perovskite's regenerative quality, increased light absorption, and its

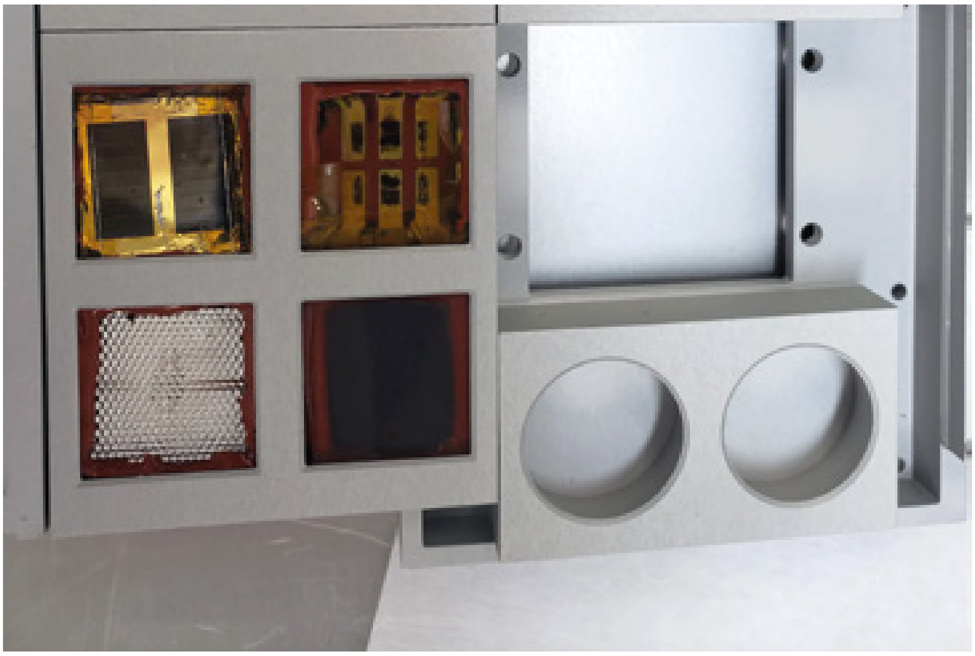

Figure 3: Image to show the perovskite solar cell tested in space by NASA

lightweight design could prove extremely valuable, suggesting that perovskite cells could power bases on Mars and beyond. NASA's willingness to work with private companies as well as their vision for the future, for sustainable energy development be prioritised to decrease green-house gas emissions all contributes towards protecting earth from global warming.

Perovskite cell's efficient and lightweight design facilitates potential applications in the military, transportation, and space exploration, however, issues with its stability, lifespan, and toxicity could discourage investment and slow progress. The development of perovskite cells was influenced by the significant energy required to produce silicon cells. With humanity's growing obsession of space, perovskite solar cells have the potential to power more than just a colony on Mars, but the future.

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Applying polymer nanocomposites: Taking a 'detour' towards a more sustainable future in the ever-growing transport dector

Words by Max Whittle (Year 12)

Chemistry

Approximately one-fifth of the global CO_2 emissions can be attributed to the rapidly evolving transport sector and hence, whilst the industry is a necessity to everyday life, it functions as one of the most significant contributors to pollution worldwide. With this in mind, scientists have dedicated countless hours towards developing new technologies that can increase the environmental efficiency of motor vehicles. One of the most exciting innovations in recent years is polymer nanocomposites (PNC), which serve to increase the structural efficiency of motor vehicles and hence, reduce the environmental impact in order to benefit society.

Firstly, with respect to the transport sector, most vehicles operate by using combustion engines with there being an estimated 1.4 billion combustion engine vehicles worldwide. These engines produce energy via an exothermic combustion reaction which involves the burning of a fuel in the air to produce carbon dioxide and water, as seen in the equation below:

Fuel + $O_{2(g)} \rightarrow CO_{2\,(g)} + H_2O_{(l)}$

Subsequently, the production and release of carbon dioxide from these engines results in an increased atmospheric greenhouse gas concentration and hence, contributes to global warming – a phenomenon that has the potential to evoke dire consequences for the environment: heat waves, increased extreme weather events, rising sea levels, and altered precipitation levels.

To address this issue within the automotive industry, PNCs have been considered. PNCs are a type of polymer – a large molecule with multiple long chains of monomer repeating units (Figure 1). These polymers can be both natural and synthetic, ranging from proteins and DNA to polyester and polyethylene.

Moreover, PNCs are also a type of composite material. Composites are formed through the combination of two or more different substances to create a new material with superior properties to the respective constituent substances. These constituent substances can be classified into two categories: the matrix, and the reinforcement material which is immersed within the matrix. Generally, the role of the matrix is to provide the shape and determine surface quality, whereas the role of the reinforcement is to provide strength, stiffness, and increase the mechanical characteristics of the composite.

More specifically, composite materials can be classified by the properties of their constituent substances. Hence, if the reinforcement fibre utilised in a composite material has an external dimension that measures less than 100 nanometres (nm), then the composite is classified as a nanocomposite material. Additionally, composites can be classified by the material that is utilised for the matrix thus, polymer composites contain a matrix that is comprised of polymer fibres; these polymer matrices can utilise both thermoplastic and thermosetting polymers. Ultimately, PNCs are a small subset of composite materials that contain both a nanofiller – a nanomaterial used as reinforcement – and a polymer matrix, providing increased physical properties in a lightweight form.

The rapidly increasing fleet of global vehicles and subsequent environmental consequences have influenced the impetus to utilise new, scientific innovations as a means of increasing the ecological suitability of motor vehicles. The United Nations predicts an increase in the number of global vehicles to approximately 1.5 billion by 2030 further increasing the volume of greenhouse gas emissions attributed to motor vehicles – currently 18% of CO_2 emissions in Australia. Furthermore, because of the importance of the transport sector in society, employing approximately 15 million workers each year, the scope for downsizing the sector is limited. Instead, increasing the environmental efficiency of vehicles is paramount in the effort to reduce global warming and the subsequent ramifications. Consequently, various types of PNCs, such as carbon nanotubes dispersed in a conjugated polymer and nylon-6 intercalated layered clay platelets, have been implemented in motor vehicles to increase their mechanical characteristics. This benefit in mechanical characteristics has

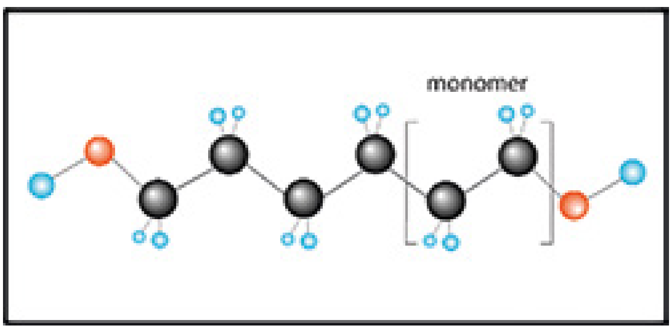

Figure 1: Diagram of a generic polymer and its monomer subunit.

permitted a reduction in the total vehicle weight, resulting in improved fuel economy and decreased exhaust emissions, thus reducing the environmental impact. Furthermore, the environmental and economic implications of fossil fuels – petrol and oil – have influenced the implementation of PNCs in motor vehicles. Fossil fuels are a finite, non-renewable resource and hence, over time, are rapidly becoming scarce and expensive. Consequently, this has influenced the use of PNCs, such as the combination of polymers and carbon nanotubes to reduce vehicle weight and hence, decrease fuel expenditure, thus prolonging the finite stores of petrol and oil. Critically, PNCs in the transport sector are both improving the environmental suitability of the world's vehicle fleet and reducing the expenditure of finite fossil fuels. Ultimately, PNCs have been influenced by both environmental and social factors and in turn, are evolving the transport sector for the better.

The extensive application of PNCs to benefit the automotive industry exemplifies the relationship between scientific innovation and wider society. In recent years, PNCs with various nanofillers and polymer matrices have been implemented into the design of motor vehicles: PNCs can be utilised in the engine cover to reduce weight by almost 20%, in exhaust systems and catalytic converters to reduce emissions, in vehicle tires to achieve increased traction with decreased overall weight, in paint covers to elicit greater weather resistance, and in fuel cells to increase hydrogen storage abilities. This exemplifies the capacity of PNCs to be applied in a variety of vehicle components to improve the overall vehicle performance and hence, benefit the consumer and the environment. In addition, due to the enhanced properties of composite materials, PNCs exhibit beneficial characteristics that allow them to reduce the use of the often expensive, metallic parts in a motor vehicle, thus permitting these metals to be utilised in other sectors. Ultimately, the potential applications of PNCs in a motor vehicle are plentiful, ranging from the mechanical systems to the outer paint. Hence, PNCs present both a viable and effective means of improving motor vehicles for the betterment of society.

Nevertheless, there are many critical limitations of PNCs that inhibit the benefits that this innovation can evoke in the transport sector. Firstly, due to the rising cost of the raw materials used in PNCs in comparison to traditional materials such as steel or aluminium, the production cost of motor vehicles with PNCs continues to increase and in turn, limits the acceptance of this technology in society. Furthermore, this increase in production cost is exacerbated by the inherent demand of the automotive industry, inducing the challenge of maintaining a reliable and cost-effective supply for PNCs. Moreover, there is currently a lack of standards and regulations regarding PNCs and hence, there is no guarantee of the safety and quality of certain PNCs, limiting their application in automobiles due to the plethora of safety requirements in the industry. In addition, composite materials are extremely difficult to recycle due to their heterogeneity and hence, require the separation of the composite back into its constituent materials before recycling. Therefore, PNCs face the severe limitation of being both difficult and costly to recycle and thereby, are often disposed of in landfill. Ultimately, whilst there are many limitations to PNCs, the potential environmental and economic benefit they pose partially outweighs these limitations and hence, efforts are being made to overcome the aforementioned setbacks.

Critically, despite the numerous benefits of PNCs in the transport sector, they are currently not widely available in the industry and hence, the commercialisation of PNCs functions as a central aim in the future of this technology. There are many proposed strategies and innovations that are intended to quickly commercialise PNCs: the production of cheaper, higher volume PNCs to meet demands; the development of more effective recycling techniques; further refinement of the PNC synthesis process, and the additional testing and evaluation of PNCs. Moreover, the most exciting innovation in the PNC field is the incorporation of green nanofillers and green polymer nanocomposites which utilise natural materials such as cellulose. The use of ecological materials in PNCs addresses the key limitation of PNCs being disposed of in landfill and thus, results in a nontoxic material with little impact on the environment. In summary, the commercialisation of PNCs is a highly researched issue in the scientific community, with many strategies and innovations suggesting an exciting future for PNCs in the commercial automobile space.

Overall, the focus on PNCs in the automobile industry has been influenced by the severe environmental impact of the currently expanding transport sector and hence, the need to improve the environmental suitability of vehicles. Importantly, PNCs have a wide variety of applications in the construction of a motor vehicle however, this is limited by cost, inefficient production methods, and the difficulty of recycling PNCs. Ultimately, despite the limitations of PNCs, they offer an exciting opportunity to make further inroads into the environmental improvement of the transport sector.

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1990s

In 1996, Dolly became the first cloned mammal, sparking debates about the future of cloning and genetics

The use of biosurfactants to clean up oil spills

Words by Owen Chen (Year 11)

Chemistry

Oil is a valuable resource in modern society as it is used for important processes such as heat and electricity generation. It is often harvested from remote places such as the ocean. The process is not without risk, with oil spills frequently occurring. Nearly 2.7 billion litres of oil is spilled into the ocean each year, causing significant harm such as pollution and wildlife poisoning. Current oil spill treatments such as absorbents are inefficient, and others such as chemical dispersants often have detrimental effects that outweigh their benefit. An international team of scientists have developed a new method of treating oil spills using biosurfactants, and initial results indicate they may be both more effective and more environmentally friendly than existing treatments.

Oil is mostly made up of complex hydrocarbons, which are large molecules consisting of hydrogen and carbon. Hydrocarbons are covalently bonded, and so they are attracted to each other through dispersion forces (formed by the temporary polarisation of electron clouds) which keep them together. The resulting attraction between the hydrocarbons results in the oil having surface tension.

The bacteria *Pseudomonas aeruginosa* is placed into oil, where it begins to produce biosurfactants. These biosurfactants surround hydrocarbon molecules disrupting the dispersion forces between them (Figure 1). This lowers the surface tension of the oil, and the hydrocarbon molecules separate from each other. In this form, they are much safer as they will more easily disperse into smaller volumes that cannot cause significant damage. Individual hydrocarbons are also easier for microorganisms to metabolize into more harmless molecules such as methane.

A difficulty that arose was identifying an appropriate biosurfactant to use, as thousands of unique biosurfactants exist each with varying effectiveness. Testing all of them would have been incredibly time consuming, and thus the research team used the results from a previous study which had identified rhamnolipids as generally being effective oil dispersants. This significantly reduced the scope of their research as they could focus purely on different types of rhamnolipids. Consequently, a bacterium (*Pseudomonas aeruginosa*) producing the desired biosurfactant was found in a relatively short time.

Moreover, it was also crucial to obtain enough biosurfactant for testing. To simulate accurate oil spills, the researchers used over 100 litres of ocean water containing oil during trials. Such a large volume of oil required a large amount of biosurfactant and therefore bacteria, which the team did not have readily available. Growing enough bacteria to use for testing would have required significant time and money, so the scientists relied on pharmaceutical companies to produce such bacteria on mass. Due to the established relationship between the team and the companies, they were able to purchase large quantities of bacteria at a considerable discount of approximately $65 per ampoule. This greatly accelerated the testing process as the team could have bacteria brought to them very quickly. For perspective, the required bacteria (*Pseudomonas aeruginosa)* sells at retail for approximately $190 per ampoule, clearly showing that the price reduction for sourcing the bacteria was essential for large-scale testing.

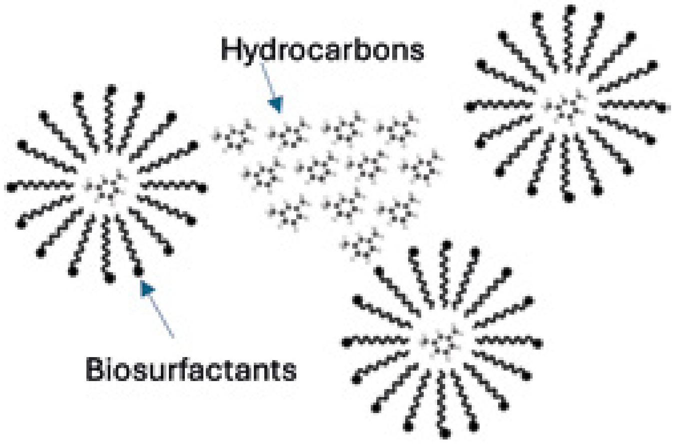

Figure 1: Emulsification of hydrocarbons through biosurfactants

The development of the biosurfactant was also informed by regulations and policies in different countries. While the biosurfactant used was largely chosen for its effectiveness, other factors like maritime laws were also taken into consideration. Different countries have different laws on what oil spill treatments are permitted, varying in requirements like biodegradability and toxicity. Additionally, different countries have different testing regulations for new treatments before they are approved, which informed the types of testing the team used. For instance, oil spill dispersants in Australia must be tested against reference oils before they can be approved. The researchers took these laws into consideration when choosing their biosurfactant and used these regulations as frameworks for their testing methods. If they had not done this, the use of this biosurfactant might have been prohibited in some countries, resulting in limited global applicability.

The successful implementation of biosurfactants to treat oil spills will have several advantages. One such benefit is that it will reduce illness from contaminated food. Fish that live in oil-contaminated waters will ingest oil from spills, where it will remain in the fish for years without breaking down. When humans eat contaminated fish, the oil from the fish can cause significant organ damage and potentially death. Since using biosurfactants to treat oil spills will increase the rate that microorganisms metabolize oil, oil will break down more quickly. This will reduce the number of contaminated fish, resulting in fewer people becoming sick. This is especially beneficial for people living in coastal regions who often have diets dominated by seafood and are therefore most vulnerable to oil poisoning from this source. Using biosurfactants to treat oil spills will also boost agricultural economies. When oil spills are severe, governments will usually ban fishing in parts of the ocean completely. This is detrimental to local fisherman who rely on their local waters for their income and cannot afford to fish elsewhere. Since biosurfactants are more effective than other oil spill treatments, they would clean contaminated waters faster which would reduce the revenue lost due to spills. This benefits fisherman and their respective communities as their source of income will be much more stable.

To summarise, biosurfactants are a new oil spill treatment that can outperform all current treatment alternatives. Once approved for commercial use, biosurfactants will improve the lives of many for years to come.

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2000s

The Human Genome Project mapped our DNA, revealing the blueprint of life and paving the way for personalised medicine

Sustainable production of hydrogen using solar power and Biochar

Words by Sam Heuzenroeder (Year 12)

Chemistry

The use of fossil fuels for energy, such as coal, gas, and oil, are by far the greatest contributors to climate change, as they are responsible for over 75 per cent of global greenhouse gas emissions as well as accounting for approximately 90 per cent of all carbon dioxide emissions. Therefore, society needs to reduce their reliance on fossil fuels, and look towards more environmentally sound alternatives, such as using hydrogen gas as a fuel source.

UIC engineer Meenesh Singh recently led a team at the University of Illinois Chicago to make a breakthrough regarding the use of a new method to produce hydrogen gas, utilising solar power and agricultural waste. Hydrogen gas is at the forefront of sustainable and clean energy, and its uptake is anticipated to grow immensely in the future, with its demand projected to increase by 125 to 585 million tonnes per annum by 2050.

Hydrogen gas can be produced from the electrolysis of water; the process in which electricity is applied to water, splitting it into hydrogen gas and oxygen gas. This is shown by Equation 1.

Equation 1: $2H_2O \rightarrow 2H_2 + O_2$

However, this is an energy intensive process when performed on an industrial scale, as fossil fuels are primarily used as the source of the electricity, which releases significant amounts of carbon dioxide when they undergo complete combustion. Currently, 95% of all industrial hydrogen gas production is from the steam reformation of natural gas. One of the most common technologies for smaller scale electrolysis is proton exchange membrane-based electrolysis, or PEM, due to its superior production rate, as well as relatively low carbon emissions in contrast with industrial methods. Although, PEM based systems are highly costly as they require platinum group metals, which are very rare.

Singh's team utilised a PEM based system adapted from a recent discovery made by a team of scientists at the Ulsan National Institute of Science and Technology. This team discovered that introducing a carbon source, such as lignocellulosic biomass, which is plant matter consisting of polysaccharides and lignin, into the electrolysis as a reducing agent drastically lowers the voltage required (by 600%), as water is a relatively poor reducing agent. Singh's team extended this idea into using a similar PEM based system, however substituting the biomass with a carbon-rich solution of agricultural waste and sulfuric acid, which the team has labelled as "biochar".

Figure 1 displays the PEM-based system that Singh's team used. At the anode, water within the biochar will oxidise elemental carbon to carbon dioxide, as shown by Equation 2.

Equation 2: $C + 2H_2O \rightarrow CO_2 + 4H^+ + 4e^-$

Furthermore, the sulfuric acid present in the biochar will ionise and force protons through a semi permeable membrane. The protons will then be reduced by the electrons located on the negatively charged cathode. This will form hydrogen gas, as shown by Equation 3.

Equation 3: $2H^+ + 2e^- \rightarrow H_2$

The overall equation for this process is represented below by Equation 4.

Equation 4: $C + 2H_2O \rightarrow CO_2 + 2H_2$

This discovery encourages a new frontier of experimentation with the production of clean hydrogen gas, particularly in Singh's team as they utilised a similar method of PEM based electrolysis. Another influential factor is how agricultural waste is a significant water pollutant. This water pollution can lead to serious illness in both livestock and humans if the water is consumed. Furthermore, the use of polluted water as an irrigation source may also be detrimental to crops and their growth. Agricultural waste is also a notable source of methane emissions, which contributes to global warming. Livestock emissions account for approximately 32% of all anthropogenic methane emissions, therefore being able to repurpose this waste will be integral in reducing methane emissions, and hence, reduce the impact of global warming. Ultimately, these factors have been instrumental in influencing Singh's team's discovery, and consequently, it holds the potential to drastically reduce methane emissions within the agricultural sector.

This new technology has many potential industrial applications which will contribute to sustainability and reduction of greenhouse gas emissions. The typical method of water electrolysis to produce hydrogen gas is, once again, heavily reliant on fossil fuels. Therefore, by phasing out this environmentally harmful process, and instead replacing it with Singh's PEM-based system on a large scale would be much more environmentally sound and will actively help to mitigate climate change. Currently, the application of this technology on a larger scale is not yet a completely viable option - PEM-based systems are primarily used for smaller scale hydrogen production. Furthermore, the team has not conducted any larger scale experiments utilising this technology at this stage. Therefore, unforeseen problems with up scaling this technology may arise, which could impact its real-world application. Another limitation of this technology is that carbon dioxide is still produced, shown in Equation 2, albeit significantly less than traditional methods of hydrogen gas production. This means that this new process involving the use of biochar is not net-zero in terms of carbon dioxide emissions, but still a drastic improvement over current techniques.

In addition, the carbon dioxide that is produced from the oxidation of the biochar can be captured, which creates a range of economic opportunities. It can be chemically converted into other compounds such as ethene, or it can be repurposed, as Singh himself recommended, using it to carbonate beverages. Therefore, despite how this new process still produces harmful greenhouse gases, this can be mitigated through repurposing these gases into new products.

The discovery of this new technology, if implemented and scaled up into industrial hydrogen production, will have many implications for society. Firstly, farmers will be faced with new economic opportunities to open up new streams of revenue. Singh's team's PEM-based electrolysis utilises and requires biochar, which is made from a variety of agricultural waste. More specifically, the team used sugarcane bagasse, wastepaper, hemp waste, retail cow manure and cow manure from farms, some of which is burnt off, further harming the environment through carbon dioxide emissions. Therefore, the industrial application of this new method will increase demand for the aforementioned agricultural waste, and potentially others which have not been experimented with, whilst limiting the environmental ramifications of these agricultural wastes. Farmers will be able to sell off the waste produced from their respective practices for profit, and hence they will be able to allocate some of this profit to invest into new technology, increasing their output. This will help to address food shortages by making goods derived from farms more abundant, which will lead to meat, vegetables and grain prices falling. Lower prices will benefit lower income households, as they will be more able to purchase healthy and fresh produce. In addition to this, using agricultural waste to produce hydrogen gas will reduce carbon dioxide emissions, as previously discussed. Moreover, as this will actively reduce global warming caused by the enhanced greenhouse effect, the melting of ice caps will be slowed. As a result, the rising of sea levels will decelerate. A benefit of this is that communities that are situated close to coastlines will be less exposed to flooding in the future. Ultimately, this new technology will not only reduce carbon dioxide emissions, but such a reduction will subsequently have a variety of cascading impacts throughout the economy.

Overall, the work of Singh's team at the University of Illinois Chicago is potentially significant from an environmental and economic standpoint. Not only will this new process of water electrolysis greatly reduce carbon dioxide emissions, but it diversifies the process of hydrogen gas production by reducing the current reliance on fossil fuels within the industry. This breakthrough, if implemented, will also greatly benefit the agricultural sector, as it creates a new stream of revenue for farmers which is driven by the demand for agricultural waste. Nevertheless, this technology is currently still limited to smaller scale use, hence scientists will need to conduct further larger-scale experiments to extend this technology further.

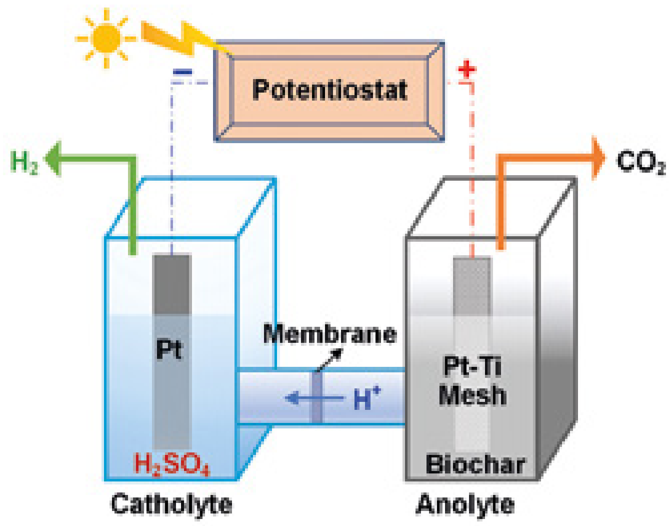

Figure 1 displays the team's apparatus which was used to make the discovery

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The laser interferometer gravitational-wave observatory

Words by Ethan Retnaraja (Year 12)

Physics

The "Laser Interferometer Gravitational-Wave Observatory" or LIGO, is a dedicated twin-site facility that detects and studies astrophysical gravitational waves by exploring the properties of light and space, from which data for research in fields from astronomy, cosmology, nuclear physics to astrophysics is generated. LIGO itself consists of two founding observatories 3000km away, both located in the US: one in Livingston (LLO) and the other in Hanford (LHO), and is staffed by researchers and physicists from Caltech and MIT. Initial research at LIGO was expanded by incorporating multiple instruments to detect any indicative light sources alongside gravitational waves so that a probable light source can be located by the electromagnetic astronomers. Now, LIGO has sister observatories called Virgo, KAGRA and GEO600 in Italy, Japan and Germany, respectively. This has enabled LIGO's mission to be expanded from merely detecting gravitational waves to a greater exploration and understanding of, and contribution to, the fundamentals of science as well as a deeper, more profound insight into the origin of the universe and its evolution.

Gravitational waves are ripples in the fabric of spacetime, which are caused by some of the most violent and energetic occurrences in the universe. These cosmic ripples travel at the speed of light and in all directions from their origins, thus providing clues on the nature of gravity and space fabric. Since Albert Einstein first predicted the existence of these waves in 1916 when discussing his Theory of General Relativity, some of the strongest detections of gravitational waves from LIGO have been from cataclysmic events such as colliding black holes, supernovae and neutron stars colliding. Other origins of gravitational waves have been attributed to neutron stars rotating and gravitational radiation emitted from the Big Bang.

Gravitational waves are detected by interference of light waves with the use of interferometers at the LIGO, Virgo, KAGRA, and GEO600 facilities. Each of these investigative devices, illustrated by Figure 1, consist of a laser emitter (a), a beam splitter (b), two mirrors (c) and a photodetector (e and f). A laser beam is first split by a beam splitter into two travelling down equal arms then reflected by a mirror on either side to go through identical chambers before recombining with its intensity measured as interference. When two light wavelengths are 'in phase', their troughs and crests line up and are amplified (f), resulting in a constructive interference. If the two wavelengths are 'not in phase', their troughs and crests not only do not line up but also cancel each other (e), causing a destructive interference.

Normally, each arm of the laser has light wavelengths that are in phase, producing constructive interference when the beams meet again at the detector. However, the presence of gravitational waves would contract and squeeze the space of the arms in which the split beams travel, altering their wavelengths and making them 'not in phase', and thereby creating destructive interference. There are two arms of 4 kilometres each at both of the LIGO's US locations. Such extraordinary lengths are needed to help pinpoint and prove the presence of long-distance gravitational waves by maximising its signal while minimising the instrumental and environmental noises and Earth's vibrations.

The US National Science Foundation Laser Interferometer Gravitational-Wave Observatory (NSF LIGO) is the largest amongst a group of gravitational wave observatories which form the LIGO Scientific Collaboration (LSC). As an umbrella organisation, the LSC engages over 1200 scientists from over 100 institutes in 18 different countries such as the US, Australia, India, China and the UK. This global network and alliance underpin three distinct goals: to manage and operate the laboratories; to develop better and more sensible gravitational wave detectors; and to advance this field through research and education. Essentially, the work of these research groups enables LIGO's continuous operations, from which data is generated, analysed and utilised for furthering gravitational wave studies. LIGO's internal collaboration between LHO and LLO verify data generated from the two sites to identify potential signals. A notable international partnership is the LIGO-Virgo-KAGRA (US-Italy-Japan) collaboration which involves the combining of the data from the multiple gravitational wave detectors, done to increase the confidence in the signals detected and allow for a more precise measurement of the source parameters.

Equipped with a 3km interferometer, the Virgo observatory in Italy is operated by the European Gravitational Observatory and funded by the National Institute for Nuclear Physics (Italy), French National Centre for Scientific Research (France), and the National Institute for Subatomic Physics (Netherlands). The KAGRA observatory has an underground, 3km interferometer located in Japan and operated by the Institute for Cosmic Ray Research (ICRR), the High Energy Accelerator Research Organisation (KEK), and the National Astronomical Observatory of Japan (NAOJ) with funding from the Japanese Ministry of Education, Culture, Sports, Science and Technology (MEXT). As branches of the LSC, the Virgo and KAGRA Observatories are operated and managed by the Virgo and KAGRA collaborations, respectively. Beginning in 2021, all three entities have been carrying out joint analysis of available data sets and co-authoring observational result papers. The collaboration has yielded several positive data sets such as the recent detection of waves from GW230529, a merging of an unknown compact object and a neutron star.

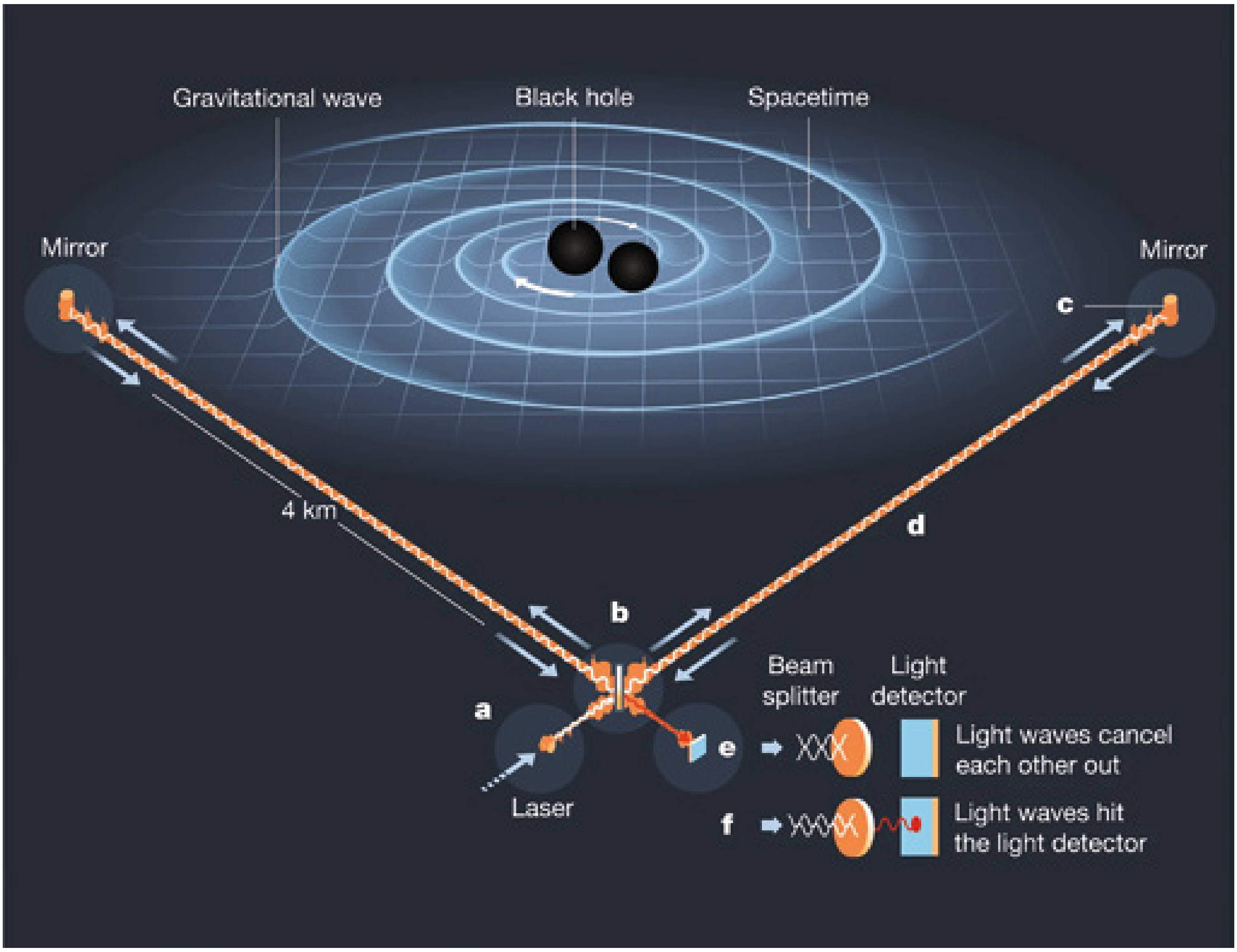

Figure 1 A diagrammatic image of a laser interferometer

LIGO, while being instrumental in the detection of gravitational waves, has limitations which impede on its ability. The LIGO-Virgo-KAGRA collaboration's geographical separation between the three research facilities present challenges which include time zones difference and cultural barriers. LIGO and its sister facilities are extremely sensitive to other sources of noise such as seismic, thermal and quantum which make it difficult to detect the faint sources of the gravitational waves. LIGO currently has a relatively small maximum detection range of 180 megaparsecs which restricts its detection beyond that range, meaning detection of the events outside the range could potentially be missed. While this covers many galaxies beyond our own, this is still small compared to scale of the observable universe, which is over 14,000 megaparsecs across. The facilities can also be subjected to the natural disasters. In January 2024, a 7.6 magnitude earthquake struck near the KAGRA site, damaging all nine of the mirror suspensions along with other damages. While majority of the KAGRA facility has been repaired, reconstruction is still ongoing, which is impeding on the ability of KAGRA to detect gravitational waves. The largest constraint for LIGO and its sister facilities is its funding and continued maintenance by research institutions and government organisations. Limited resources could constrain the observational time as well as lengthen maintenance times and time that the observatories are offline.

The Covid-19 pandemic also slowed research by the LIGO Scientific Collaboration as contributions from various LIGO groups were reduced.

There are many possible avenues for future developments of LIGO including sensitivity enhancement, collaborative observation runs, new LIGO centre in India and exploration of new space events. LIGO-Virgo-KAGRA is currently on its fourth observing run, O4, which has incorporated new hardware, to enhance the detectors capability to detect gravitational waves. It also incorporates the application of a 'squeezer cavity' which reduces the quantum noise, allowing further enhanced detection. Lisa Barsotti, a senior research scientist at MIT who oversaw the development of the new LIGO technology', said that "we can't control nature, but we can control our detectors". The collaboration of the three observatories will also continue with the current O4 observation run as well as the planned O5. It aims to synchronize the observing runs and maximise data collection through improved locating of the gravitational source (Caltech, 2024). LIGO-India is a planned observatory that is to be located in India and join with the other observatories. Currently, it is under active consideration in both India and the US and is envisaged as a collaborative project between Indian research institutions and the LIGO laboratory in the US. Should the project commence, it will be led by four institutions: Raja Ramanna Centre for Advanced Technology (RRCAT), Institute for Plasma Research (IPR), the Inter-University Centre for Astronomy and Astrophysics (IUCAA) and the Department of Atomic Energy (DCSEM) with help from the US and other collaborators. This would allow for further synchronisation of data, as LIGO-India would join the current collaboration of LIGO-Virgo-KRAGA. The current observation run, O4, also allows for multi-messenger astronomy by providing astronomers opportunities to not only detect gravitational waves but also observe the light from those sources. It would provide astronomers the opportunity to learn about black holes and neutrons stars, as well as the merging between themselves and each other. This would broaden the scope of scientific knowledge not attainable in conventional laboratory testing on Earth.

LIGO signifies an important milestone in the discovery and understanding of the universe. Confirming Einstein's theory of the existence of gravitational waves, it marks a pivotal step towards understanding the relationship between matter and spacetime. Despite the current advancements, LIGO has several limitations such as the inherent difficulty in detecting faint signals as well as innovating significantly advanced techniques to reduce background noises. However, the data which LIGO collects provides crucial insights into the phenomena of some of the most violent objects in the known universe, neutron stars and black holes. While awaiting more advanced technology to enhance detection of the gravitational waves, LIGO remains the collective space explorer for humanity to unlock the mystery of the universe while pioneering novel technology and inventions which have only been possible due to concerted efforts and dedicated finance internationally.

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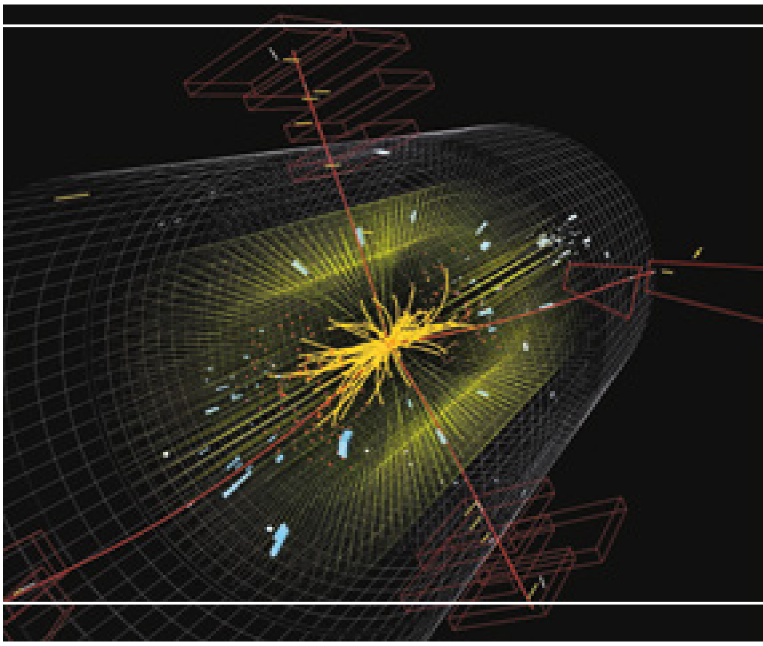

2010s

CERN discovered the Higgs boson in 2012, helping explain why particles have mass and deepening our cosmic understanding

Formula 1 drag reduction system

Words by George Karas (Year 7)

Physics

Formula 1 (F1) is a thrilling sport full of high-risk driving with speeds reaching more than 300 km/h and brutal crashes that may result from even just the smallest mistake. In 2011 the introduction of the drag reduction system (DRS) and its implementation into every F1 car has allowed for advancements in aerodynamics by creating a reduction in air drag when the rear wing is engaged by a manually controlled system.

How does DRS work?

The driver must first initiate system by pulling a trigger located in the car, after which the DRS will be activated. This causes the adjustable flaps in the rear spoiler to rotate upwards allowing air to flow easily through the rear spoiler and streamline the car, reducing the levels of drag on the rear wing (Figure 1). DRS flaps are modelled after inverted aeroplane wings. Instead of pushing the air down to create downforce allowing for increased grip and subsequently increased corner speeds, the flaps direct air upwards to create an upwards force that reduces drag and downforce. By minimising these effects, higher tops speeds can be achieved.

DRS has revolutionised F1 since its inception. One of the most challenging aspects of F1 driving is overtaking and the introduction of DRS has assisted this greatly. Before this new system, cars leading the field were at a major advantage because of the clear track in front of them, making it is much easier to gain higher straight-line speed and to stay ahead in cleaner air. However, DRS has made it easier for chasing cars to overtake, lessening this advantage. (Figure 2). A driver cannot activate the system at all times however. The rules and regulations in F1 permit that for DRS to be activated, a car must be within a second of the car ahead and inside a designated DRS zone which are usually located on the longer straights in a track. DRS is also prohibited in the first 3 laps of the race.

Most F1 fans enjoy wheel-to-wheel contests and the exciting and risky situations this presents, which the technology that the DRS system certainly adds to. The development of DRS has made F1 races a much more thrilling and evenly contested sport. It is a good example of the many technological advancements that have originated from this sport, some of which are eventually incorporated into the family car – although I am not sure DRS will be one of these!

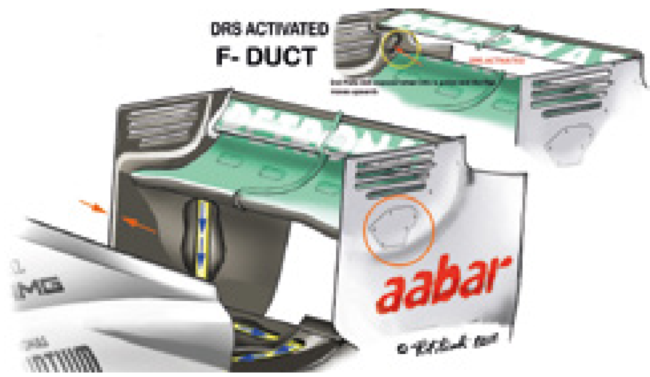

Figure 1: Schematic of activated DRS mechanisms

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Figure 2: Overtaking with activated DRS (left) in Albert Park, Melbourne

Satellite technology's role in artificial intelligence simulating glacier mass balance

Words by Michael Cook (Year 12)

Physics

Applying Artificial Intelligence (AI) to satellite measurements of the Earth's surface shows promise in predicting changes in glaciers, with the potential to outperform current numerical model-based approaches. Glacial Mass Balance (GMB) refers to the net annual change in mass of a glacier by considering its difference in accumulation and ablation, reflecting the glacier's health. Widespread negative GMB caused by climate change fuels rising sea-levels. Physical extrapolation of GMB data, which requires the resource-intensive efforts of physicists to formulate predictive trends, oversimplifies the phenomena's complexities. Consequently, led by Ren Weiwei, Chinese researchers intercompared forms of AI with geodetic GMB data to evaluate their reliability when predicting GMB based upon environmental predictive factors. Importantly, the AIs' training and evaluation relied upon satellite technologies to capture datasets fundamental to the research. Both in efficiency and reliability, AI exceeded physical extrapolative models.

The four evaluated machine-learning AIs underwent supervised training before their application, where they were provided global GMB data from the ASTER satellite observations (the dependent/target variable) and a plethora of global environmental and topographic variables (independent/predictor variables). Much of the training data came from the ERA5-Land and Randolph Glacier Inventory 6.0 (RGI) public datasets, containing a history of weather, atmospheric conditions and glacier outlines. GMB and environmental data availability has drastically increased due to progressions in remote data collection using satellites.

Geostationary satellites are optimal for consistent monitoring of a broad region of Earth, displaying general weather trends. They are launched close to the equator in an easterly direction to align with Earth's axis and direction of rotation while also saving resources. To synchronise with the period of one sidereal day, the radius of orbit from Earth's centre must be approximately 4.21×10^6 metres, as seen below:

$$T^2 = \frac{4\pi^2}{GM} r^3$$

$$\therefore r = \sqrt[3]{\frac{T^2 GM}{4\pi^2}}$$

Here:

$$\text{Period of Earth's Rotation (Sidereal): } T = 86{,}164 \text{ s}$$
$$\text{Gravitational Constant: } G = 6.67 \times 10^{-11} \text{ N m}^2 \text{ kg}^{-2}$$
$$\text{Mass of the Earth: } M = 5.97 \times 10^{24} \text{ kg}$$

Giving:

$$r = 4.21 \text{ million km}$$

So, in launch, geostationary satellites are calculated to reach this altitude to remain geographically fixed. Once at this radius, its velocity away from the Earth is overcome, and the component left is tangential to its circular path, as the satellite is launched with a horizontal component of velocity. As seen in Figure 1, uniform circular motion (UCM) is achieved because the gravitational force is towards the centre of the mass it orbits, and therefore is perpendicular to its tangential velocity.

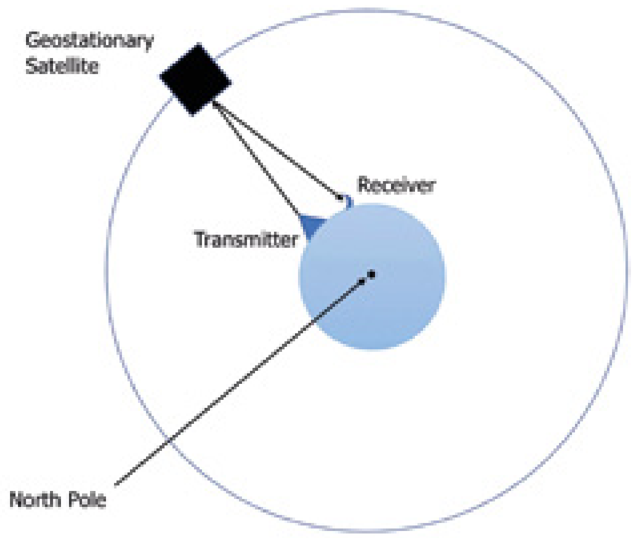

Figure 1 - UCM Orbit of Satellites

As work is proportional to cos ø, and the angle of force is always perpendicular (cos 90° = 0), there is no work done and thus, there is no change in kinetic energy and speed, which is imperative to geosynchronous equatorial orbit, as the velocity is inversely proportional to the period. Other satellites are implemented for higher detail images, as geostationary satellites' substantial radius reduces its spatial resolution.

Polar satellites orbit perpendicular to the equator, and at a low Earth orbit at 500-1500 km. Consequently, they provide global coverage of Earth instead of being fixed in relative position. At a lower altitude, higher resolution images are optimal for the GMB data collection, and beneficially, launch costs are reduced because less energy is required when launching to significantly lower radii. These satellites can be in UCM but are also launched into an elliptical orbit depending on their desired function.

After their training, the AIs were tasked with predicting the GMB of glaciers in the Manas River Basin and the Niyang River Basin as local case studies which represent continental and maritime glaciers respectively. They were given the environmental conditions of both regions from 2000-2020, and then simulated annual GMB predictions which were compared with the recorded GMB data from the period, which was accurately measured at the time using satellite geodesy.

The research provided newfound insight to further progress the combined efforts of scientists internationally involved in this field. When formulating predictive variables, a synthesis of findings founded by satellite imaging from Zhang et al. and the French Space Agency funded research from Brun et al. were considered. This allowed for a more intricate understanding of the topological factors which were interrelated to ablation and accumulation variables, contributing to the lengthy array of 60 predictors.

Thus, it is evident that the publicization and communication of global research is key in refining the application of scientific knowledge, because successful AI implementation relies upon research-informed predictive variables. Moreover, Ren discloses the limitations of these predictive variables, which further demonstrates communication as improvements can be made in future studies. He suggests refinements by considering longwave and shortwave radiation and energy balance models to increase the models' comprehensiveness.

Furthermore, shared datasets from satellite imaging were foundational in Ren's research, demonstrating the importance of international collaboration. The ERA5-Land dataset, maintained by European forecasting stations, and RGI, maintained by the Global Land Ice Measurements from Space initiative, are free and easily accessible. This facilitates global efforts to research climate change and its effects on GMB. Maintaining both public datasets requires great collaborative efforts, but specifically, the importance of international collaboration is highlighted by the RGI, as it is a global collaborative project, recording the size of all global glaciers. This requires regional collaboration, which is incentivised by offering each participating regional centre access to the ASTER dataset and assistance in large-scale image analysis algorithms. The RGI's importance in Ren's studies and others alike accentuates the strength of collaboration in fostering the advancements of research to understand and predict climate change.

The new technology of AI improves the efficiency of predicting GMB and has the potential to replace physical models. Currently, GMB simulation models require substantial computational capacity and time. The process-based physical models are what makes manual predictions resource-intensive, utilising complex energy balance models that require laborious parameter calibration for any degree of accuracy. So, improvement is required to more efficiently understand climate change's relationship with glacial melting. Ren's evaluation supports the decision-tree AI's potential for this task. Once trained, this AI can extrapolate current data to explore the effects of climate variations more precisely, allowing for predictions of the complex relationship between climate change and GMB. However, the AIs showed some unreliability, underestimating high GMB target values and visa-versa. This was speculated to be caused by the insufficient spatial resolution of the ERA5-Land images, which therefore could not illustrate minute glacial events, and was found to cause data biases.

Essentially, the general paradigm shift from numerical calculations based on physical laws, to predictive AI, trained on environmental observations, demands more detailed environmental data collection. Hence, there is a requirement to move past in-situ observations and rely on remote sensing tools to supply AI with data. Ongoing development of remote sensing technology allows for better environmental data. Modern satellites are equipped with advanced sensors to capture a larger variety of environmental factors, continuing to increase cost performance, allowing for more abundant environmental datasets. Specific to GMB observation, synthetic aperture radar (SAR) techniques implement echoed electromagnetic waves, accounting for the angular movement of the radar as it moves to yield higher resolution images. Recently, the spatial resolution has increased to sub-meter scales, potentially minimising the limitation of image quality. More widespread use of SAR has become feasible through its miniaturization as a satellite, creating more efficient, low Earth orbit systems which provide global coverage. With these progressions, utilising satellite technology, AI may become more reliable due to increased data quality.

Considering its out-performance of human predictions, AI undoubtedly has a role in GMB simulation especially once its limitations are addressed, along with the advancement of remote sensing technology. Similar AI algorithms will be applicable to a multitude of scientific fields requiring complex models. Glacier health is important to maintain sea-levels, but also is vital to their specific regions. Ren's studied local glaciers are freshwater reservoirs which fuel the socio-economic growth in High-Mountain Asia. Hence, the future application of AI in GMB predictions will be able to advise scientists on how to best act to preserve glaciers, which in turn helps maintain sea-levels, the economy, and water-sources of many regions. GMB predictions will also aid in predicting hydrological models and warn of glacial lake outburst floods. In future, the progression of technologies such as satellites to enable more detailed recordings of environmental data will only improve the AIs reliability and assist other fields requiring global environment measurements. With more confident AI models, the simulation of potential future environments can serve as indisputable evidence which holds governments and corporations worldwide accountable for their environmental impacts because the consequences of their actions are calculatable and preventable.

AI is a promising solution that increases the reliability and reduces the computational needs of models. The development of better remote sensing will enable the formulation of stronger AI models that can be used to predict GMB outcomes globally. GMB simulations are highly relevant to assessing and mitigating the risks of climate change, supporting scientists in comprehending the convoluted relationship between climate and glacial melting.

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2020s

An AI algorithm is developed to detect definitive biosignatures as evidence of past life

New Horizons

Words by Zach Floreani (Year 11)

Physics

The quest for unravelling the mysteries of the cosmos has driven humanity to push the boundaries of scientific and technological advancements. As space exploration ventures deeper into the vast expanse of our solar system and beyond, the need for reliable and long-lasting power sources has become paramount. The development of the radioisotope thermoelectric generator (RTG) has emerged as a ground-breaking solution, enabling missions like New Horizons to venture into the farthest reaches of our celestial neighbourhood and unveil the secrets of distant worlds.

Historically space exploration has been powered by the usage of solar panels and before those, chemical batteries. The first use of solar panels in space travel was during the launch of the Vanguard 1 satellite by the United States in 1958, harnessing solar power from the sun, capturing, and converting it into electricity, using photovoltaic cells. The benefit of using solar power is that it is infinitely renewable due to the sun being a constant source of energy in the solar system. The only limitation with this is that during deep space missions like New Horizon, the solar panels are significantly less efficient due to the distance from the sun. This is due to the Inverse Square Law of Light, which states the intensity of the light to an observer from a source is inversely proportional to the square of the distance from the observer to the source, given by the formula $\frac{S}{4\pi r^2} = I$, where S is the strength of the source, *I* is the intensity of the light or in this case the energy, and $4\pi r^2$ is the area the light is being shared across at that distance.

Figure 1 displays how as the distance away from the sun doubles by the radius of the sun, the intensity of the light will be a quarter of what it would be at the closest point, this is because the light is spread across a larger area.

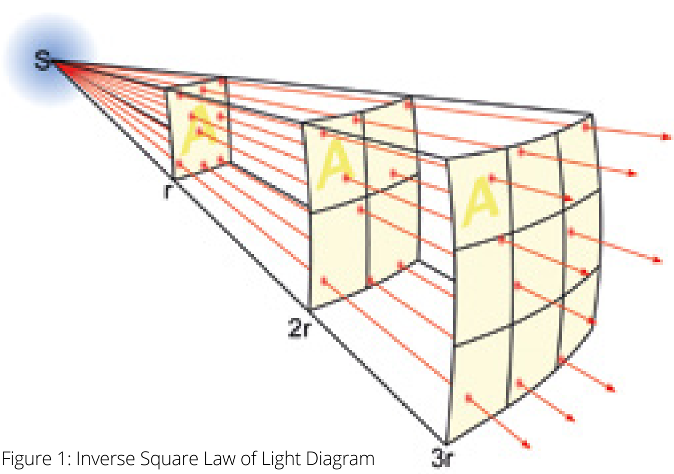

Figure 1: Inverse Square Law of Light Diagram

Due to this, NASA have employed the usage of a nuclear Radioisotope Thermoelectric Generator (RTG) (Figure 2) to power the New Horizon to travel to deep space in a fly by mission of Pluto. The RTG is powered by the transformation of heat from the natural radioactive decay of plutonium oxide into electricity. This enables the spacecraft to travel deeper into space as it is not bounded by its distance from the sun.

The development of the RTG to be used in deep space missions, was derived from the scientific theory, the inverse square law of light. This law explains why the usage of solar energy is near impossible when space missions go as far as Pluto. Applying the same concept in figure 1 to the distance between the Sun and Pluto, and the Earth and Pluto, you can find the relative decrease in intensity. 3.7 billion km ÷ 150 million km = 25, to 2 significant figures. Squaring this number then results in the factor the intensity decreases by in this case $25^2 = 625$, where the intensity of the light at this point is divided by such number, ie a 625 times decrease in intensity on Pluto compared to here on Earth. Due to this, scientists and engineers had to develop a different way that power can be sustained for a significant period with enough power to reach deep space, whilst not using solar energy. One way they could have done this was through the use of chemical batteries and fuel cells, however they have limited lifetimes, making them ineffective for deep space. What led to the development of the RTG for space was the discovery of thermoelectric materials that can efficiently convert heat into electricity through the Seebek effect. Materials such as telluride and silicon-germanium were used, and the availability of radioisotope fuels such as Plutonium-238, which produces heat through the process of radioactive decay, whilst having a half-life of 87.7 years, which enables a long-lasting power source to be used in deep space. The other benefit of using nuclear power, is due to Plutonium-238 having an extremely high energy density of 0.56 watts per gram compared to other fuel sources, meaning that a very small amount of fuel can provide power to the deep space vessels for decades.

The development of RTG's has led to advancements in thermoelectric materials, such as telluride, and silicon-germanium, which are able to efficiently convert heat into electricity. These advancements have led to the improvements in material properties, manufacturing techniques, and the understanding of solid-state physics. Integrating RTG's into space travel has also impacted the design and engineering of the power systems, thermal management, and radiation shielding involved with deep space missions. The ability to conduct these deep space missions has significantly impacted the research and studies of astrology and space due to new facts and information about places like Pluto and the Kuiper belt that can now be discovered due to the long lasting and efficient RTG's.

The usage of RTG's also have some negative aspects, one being the economic cost of the plutonium-238 as well as the other materials and technologies required to manufacture an RTG. Fortunately, private companies like SpaceX and Blue Origin are

Figure 2 NASA workers installing the RTG onto the New Horizons spacecraft prior to launch

now contributing to the economic viability of Mars missions. The use of radioactive materials in the RTG also raises ethical concerns regarding this technology and the missions it enables regarding the environmental impact that the plutonium-238 has on the Earth and other celestial bodies, which has ultimately led to the development of strict planetary protection protocols and safety measures.

The changes made throughout history to develop a power source that can drive missions into deep space has had a profound impact both on society and the scientific community as we continue our exploration of the outer reaches of our solar system.

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Joshua Wang (Year 7)

Jonathon Wong (Year 7)

Rishab Thairani (Year 10)

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Xavier Lim (Year 9)

Harry Paholski (Year 9)

Toby Dodd (Year 10)

Henry Yang (Year 10)

National Titration Competition (Year 11)

James Cree, Jack Zeng, Rijak Dhingra (Excellent Team)

Curtis Mundy, Samuel Commons, Harry White (Highly Commended Team)

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Caleb Tang (Year 12) First, Second and Third Prize Year 11-12 Scientific Inquiry category and 2024 Oliphant Trophy Winner

Aryan Parwal (Year 11) Second Prize Year 11-12 Scientific Writing category

Science Investigation Awards (Year 7)

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Joshua Wang (Third Place)

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