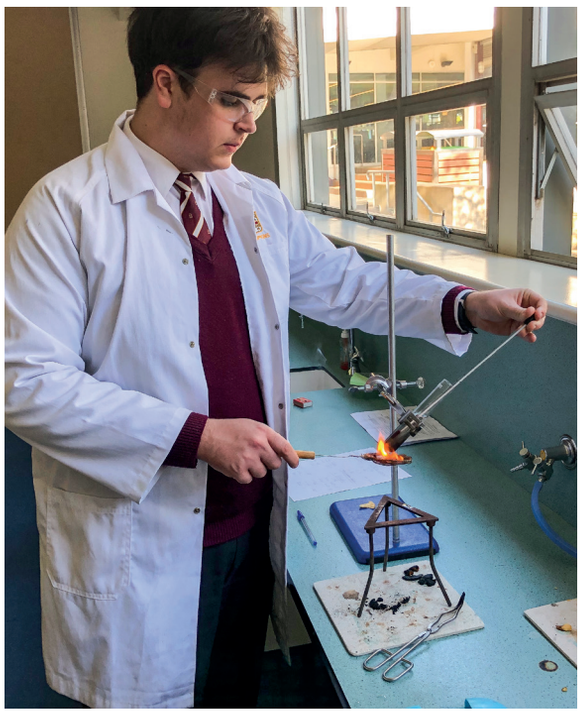
79TH EDITION

"EMBRACE THE EVOLUTION OF INTELLIGENCE"

PRINCE ALFRED COLLEGE SCIENCE JOURNAL 2023



A word from the Editor

Being an integral part of Prince Alfred College's rich history, the Science Journal enters its 79th year, after the chief editor John West commenced this tradition in 1945. The theme this year, *"Embrace the Evolution of Intelligence",* encapsulates a bold vision for the future of human society, where Artificial Intelligence (AI) fundamentally transforms the way we live and work. At its core, the theme underscores the understanding that while the changes AI brings may be profound and multifaceted, they are not inherently positive or negative. It challenges us to look beyond the binary notion of AI being either "beneficial or harmful." Instead, it encourages us, as students, to recognize that the impact of AI is contingent on how we choose to adapt and harness its potential. The theme also explores the evolving intelligence within the college community, as students gain various degrees of knowledge through their education at Princes. With a total of 22 articles included this year, the journal encapsulates all areas of science, demonstrating the broad impact of science on our day-to-day life.

This year, the journal is honoured to have Professor Lyle J Palmer (PhD FRSS) as a Guest Author who has contributed a very insightful article on future prospects of Machine Learning in the field of healthcare. Professor Palmer is a distinguished expert in genetic epidemiology and biomedical research and has made a significant impact on the field through his remarkable career. He moved to Adelaide from Toronto in 2014, accepting a position as a Professor of Genetic Epidemiology at the University of Adelaide. He has earned numerous awards for his contributions to biomedical research, such as Fulbright and Churchill Fellowships, and has a strong focus on the use of machine learning for clinical problem-solving. His article explores the use of AI in clinical diagnosis and treatment, as well as other important areas of concern such as ethics.

I wish to express my gratitude to Mr Peter Hopkins for his support and guidance throughout every phase of the Journal's development. From assisting in selecting the journal theme to keeping us informed about impending meetings, your continuous commitment to this journal is appreciated by the school and all committee members. I would also like to thank Eddie Gerald for his diligent work in designing the promotional posters as well as the front cover. Last but not least, both the Science Journal Committee and the article writers deserve our heartfelt thanks for their invaluable contributions to this momentous journal in the history of the College. Whether it was composing or editing articles or collecting fun facts, your efforts have been instrumental in making this journal a possibility.

I am very grateful to be a part of this continuing tradition led by the many impressive Chief Editors before me and I hope this young, yet energetic group of committee members all the best in their future endeavours.

Winston Huang (Year 12)
Chief Editor 2023

2023 Science Journal Committee
Back Row: Mr Peter Hopkins, Winston Huang (Chief Editor), Saverio Blefari, Lachlan McKay, Jesse Rothgrew, Aryan Parwal, Don Bui. **Front Row:** Sage Goel, Devesh Anavkar, Caleb Tang, Rijak Dhingra, Charles Tang, Noah Laforest. **Absent:** Lachlan Logan

Front cover artwork: Eddie Gerard (Year 12)

Past editors

John West, 1945

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

Bruce Chartres, 1946

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

Geoff Ward, 1947

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

Alan McFarlane, Co-Editor 1948

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

Colin Schwartz, Co-Editor 1948

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

David Prest AM, 1949

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

Bob Hale, 1950

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

Sandford Skinner, 1951

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

Barry Smith, 1952

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

Michael Smyth, 1953

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

Fred Symons, 1954

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

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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. He is currently lecturing at the Open University, U.K.

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, 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 anwent on to gain a PhD from Oxford University for research into fluid mechanics. Positions at the University of Adelaide, Aeronautical Research Laboratories in Melbourne, and the Department of Mechanical and Aerospace Engineering, Princeton University have since followed.

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 at Rockingham 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 to take up a short term role as Deputy Vice-Chancellor (Academic) at the University of Western Sydney. He has stayed on at the University of Western Sydney as Senior Academic Advisor.

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 is now a senior staff specialist rheumatologist at the Queen Elizabeth Hospital and aimed to have completed a masters degree in clinical epidemiology in 2010.

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

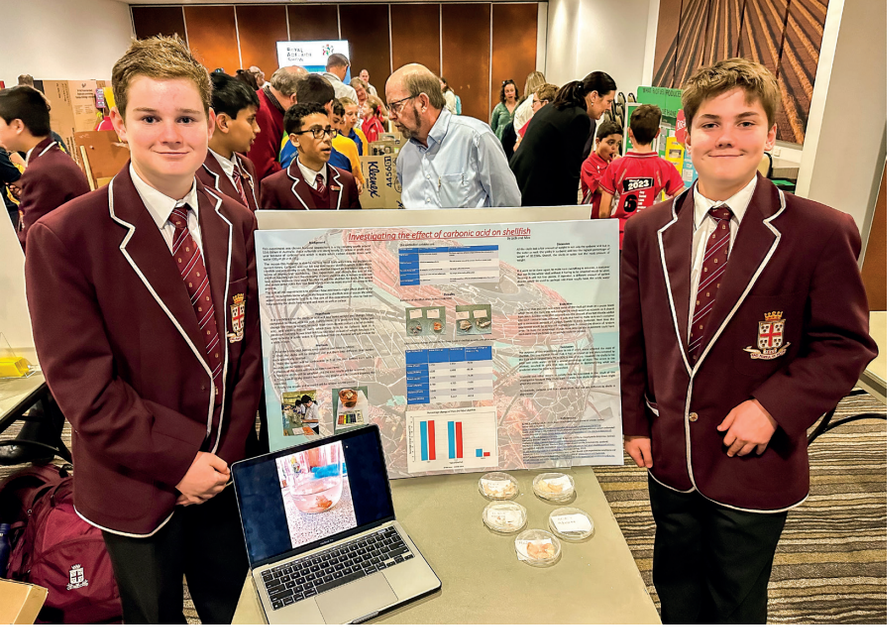
Joshua graduated from the SACE in 2020 and after contributing to the Science Journal for several years whilst at Princes he became the Chief Editor in his final year of Senior schooling. On graduating from Princes he studied Marine Biology at the University of Adelaide and was excited for what future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

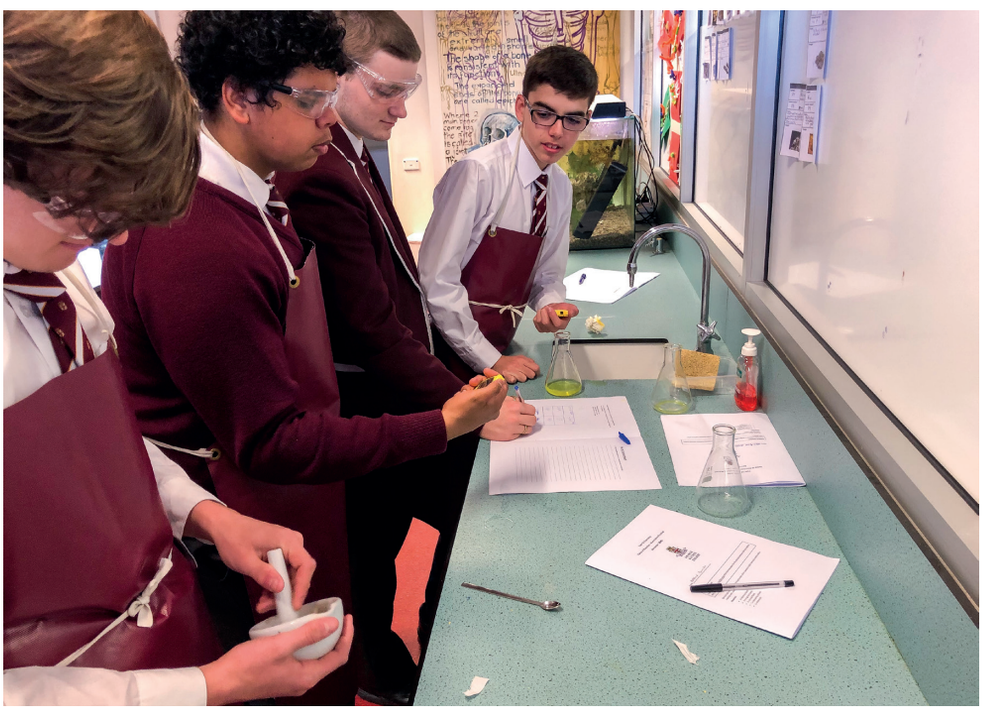
Dinan Perera, 2021

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.


Investigating the effect of carbonic acid on shellfish



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Revolutionizing Healthcare: Harnessing the Power of Artificial Intelligence in Medicine

Words by Professor Lyle J Palmer

Guest article

Introduction

We are living in interesting times. The Australian population is generally living longer and healthier lives than ever. Advances in medicine and public health have extended longevity dramatically over the last century. Concomitantly, the rate of change in technology and innovation in medicine has been exponential, as is the sheer volume of digital data now available on patients from eHealth and genomics initiatives.

However, many wicked healthcare problems remain and our lengthening lifespan, ageing population, and growing affluence have bought with them a host of new problems related to chronic diseases such as dementia, obesity, and type 2 diabetes. The major health challenges facing most developed nations are those related to the rising incidence of common, chronic diseases and the increasing complexity of their diagnosis, prevention, treatment, and incorporation into routine health-service delivery systems. Chronic diseases such as cancer and mental illness are associated with substantial long-term morbidity and mortality and are major public health problems both in Australia and worldwide. The cumulative effects of inequity, the social determinants of health, and our obesogenic environment are neither small nor insignificant; the difference in average lifespan between central Adelaide and the northern suburbs of Adelaide is an astounding 10 years.

To solve these wicked problems, new approaches to medicine and public health are needed. Genomics and other -omics technologies are one such approach and are increasingly making precision medicine a reality in areas such as oncology. Another new set of tools has come from artificial Intelligence (AI) applied to 'big data' available from electronic medical records and other digital health information.

Artificial Intelligence (AI) has rapidly evolved over the past few decades, ushering in a new era of technological advancement across various sectors. One of the fields that has benefited immensely from AI is medicine. This article will explore the profound impact of AI in the realm of healthcare, how it is transforming diagnostics, treatment, and patient care, and the ethical considerations that come with this revolutionary shift.

The Current State of Healthcare and its Challenges

To understand the significance of AI in medicine, we should first pause to consider the state of healthcare and the challenges it faces. The healthcare industry is characterized by rising costs, increasing patient loads, and a growing demand for improved patient outcomes. These challenges are placing unprecedented strain on the healthcare system and health professionals. The stark reality is that the current public clinical system in Australia and in every other country is rapidly becoming unsustainable. New approaches and better ways to analyse and make use of digital health data are urgently needed.

AI-Powered Diagnostics

Medical Images

One of the most impactful applications of AI in medicine lies in the analysis of medical images. Deep learning – a type of AI algorithm - can process and analyse medical images such as

X-rays, CT scans, MRIs, and pathology slides with remarkable precision, often achieving super-human performance (Figure 1). For instance, deep learning models can detect and classify abnormalities from ophthalmological and dermatological images, outperforming the best human doctor and allowing more accurate diagnoses and treatment recommendations for diseases such as diabetic retinopathy and melanoma (Figure 2). The work of my research group within the Australian Institute for Machine Learning (AIML) is focussed on analysing medical images using deep learning to provide more accurate and precise diagnoses and prognoses in patients. We work across many clinical areas, including ophthalmology, rheumatology, cancer, neurology, psychiatry, and respiratory medicine. As an example, we have developed a hip fracture detection algorithm using pelvic X-rays that outperforms both general and sub-specialised (musculoskeletal) radiologists in South Australia (Figure 3).

Early Disease Detection

AI algorithms can identify patterns and anomalies in large datasets that humans might overlook. This ability is particularly useful in the early detection of diseases like cancer. AI-powered screening tools can identify potential malignancies and anomalies in medical images, leading to faster and more effective treatment.

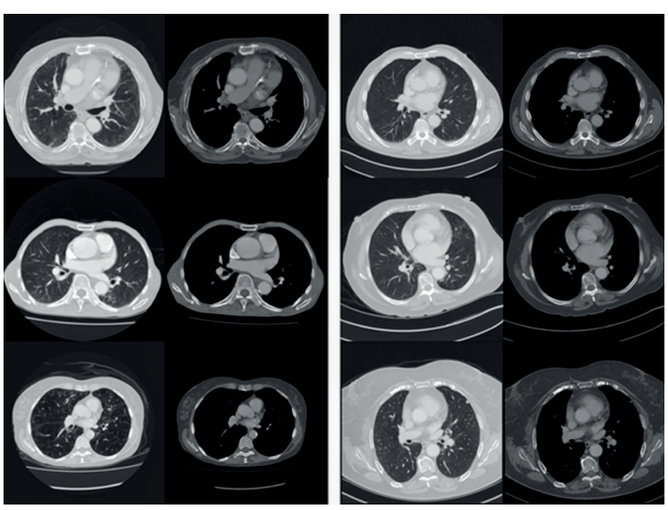

Figure 1: MRI scan.

Personalized Medicine and Treatment

Genomic Medicine

The field of genomics has been transformed by AI. Genomic sequencing generates vast amounts of data, and AI algorithms can analyse these data to identify genetic mutations, predict disease risk, and personalize treatment plans. With AI-driven insights, doctors can tailor medications and interventions to each patient's unique genetic profile. I am a geneticist by training, and it is remarkable how far we have come over the last several decades in terms of the clinical impact of genomics. For instance, around 1/3 of all intellectual disability in South Australian children can currently be explained using genomic sequencing as a diagnostic tool.

Drug Discovery

AI accelerates drug discovery by analysing extensive chemical and biological data to identify potential drug candidates. This not only expedites the development of new medications but also allows for the repositioning of existing drugs for new therapeutic applications. AI-driven drug discovery holds great promise for treating rare diseases and conditions that were previously challenging to address.

Treatment Optimization

Precision Medicine

The concept of precision medicine involves tailoring treatment plans to individual patients based on their genetic makeup, medical history, and lifestyle. AI plays a central role in personalizing treatment regimens, helping physicians choose the most effective therapies while minimizing side effects. While physicians and surgeons are often good at diagnosing disease on first presentation, doctors tend to do poorly at predicting how rapidly a disease will progress in an individual patient or what the optimal course of treatment might be.

Predictive Analytics

AI models can predict patient outcomes and identify individuals at higher risk for specific conditions. This allows healthcare providers to intervene proactively, prevent complications, and improve patient care. Predictive analytics are particularly valuable in managing chronic diseases and ensuring better long-term outcomes. For instance, an algorithm recently developed at the RAH can predict - with close to 100% accuracy - those patients likely to die within a year following a general anaesthetic.

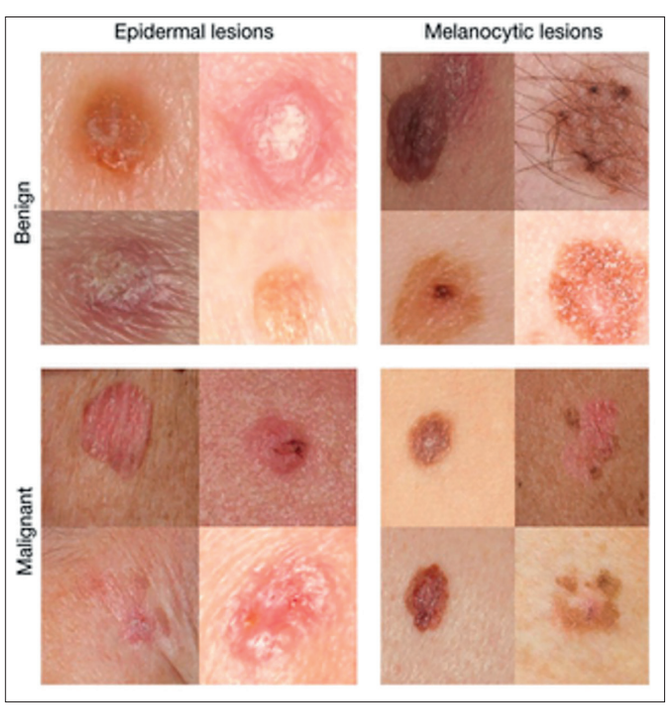

Figure 2: Skin lesions

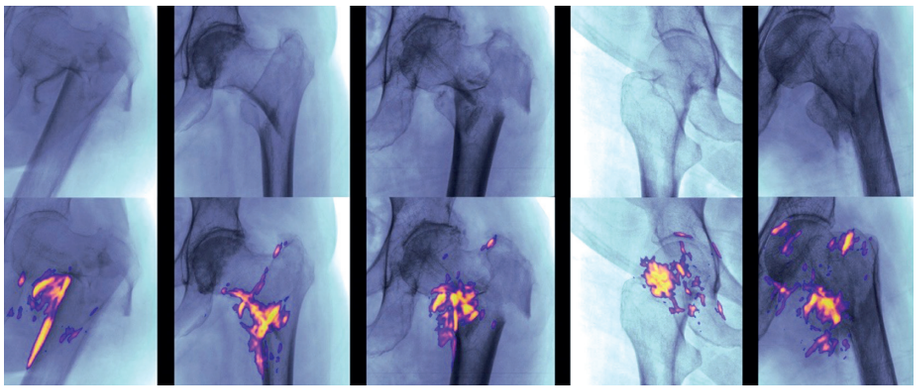

Figure 3: Hip fracture detection.

Virtual Health Assistants and Telemedicine

Virtual Health Assistants

AI-powered virtual assistants, like chatbots and voice-controlled devices, provide continuous support to patients. These virtual health assistants can answer questions, provide medication reminders, and monitor vital signs. They are especially beneficial for patients with chronic conditions who require ongoing care and supervision.

Telemedicine

Telemedicine is of particular importance in a nation such as Australia, and AI plays a pivotal role in remote healthcare delivery. Video consultations, AI-driven symptom assessment, and remote monitoring of patients offer improved access to medical care, especially in rural and underserved areas. This technology also proved invaluable during the COVID-19 pandemic, reducing the risk of virus transmission while ensuring patients received necessary care.

Ethical Considerations in AI-Powered Medicine

Medicine has a well-developed and extensive set of ethical and safety 'guard rails' to ensure new technologies are effective and safe. However, the integration of AI in medicine raises several specific ethical concerns. My team at the AIML includes a group devoted to responsible AI in medicine and this area has become increasingly prominent as AI impacts clinical practice.

Data Privacy

AI systems rely on vast amounts of patient data. Safeguarding this data to protect patient privacy is of utmost importance. Strict regulations, such as GDPR in Europe and HIPAA in the United States, govern data handling and storage.

Bias and Fairness

AI algorithms can inherit biases present in training data, which may lead to discriminatory or inequitable outcomes. Ensuring fairness in AI healthcare applications is essential to prevent bias-related disparities in patient care.

Accountability

Determining responsibility in the event of AI-related errors or adverse outcomes is challenging. Clear guidelines and regulations are needed to define accountability, particularly when AI plays a significant role in diagnosis and treatment decisions.

Informed Consent

Patients must be adequately informed about the use of AI in their medical care and give informed consent. Transparency in AI algorithms and their potential impact on diagnosis and treatment is crucial for patient trust.

The Future

We are at the end of the beginning of the impact of AI on medicine. The future of AI in medicine holds exciting possibilities. AI-aided decision support systems are already in widespread use in areas such as radiology and oncology. With ongoing advances in machine learning, deep learning, and data analysis, AI will become an integral part of patient care, diagnostics, and medical research. AI-driven diagnostics will continue to improve, enabling early disease detection with a high degree of accuracy. Personalized treatment plans, tailored to a patient's genetic makeup and medical history, will become the standard of care, optimizing treatment outcomes while minimizing side effects. Telemedicine and virtual health assistants will offer more comprehensive and accessible healthcare options, making medical services available to a broader range of patients, including those in remote or underserved areas. Furthermore, AI will play a central role in drug discovery, accelerating the development of new medications and enabling the repositioning of existing drugs for various therapeutic applications. With its potential to enhance preventative care, streamline resource allocation, and address global health challenges, AI will continue to be at the forefront of shaping a healthier future for all.

Conclusion

The integration of AI in medicine is revolutionizing healthcare delivery. From improved diagnostics to personalized treatment, telemedicine, and preventative care, AI is enhancing patient outcomes, reducing healthcare costs, and expanding access to quality care. However, it is essential to be mindful of ethical concerns, such as data privacy, bias, accountability, and informed consent, to ensure the responsible and equitable use of AI in medicine. SA already plays a leading role in AI methodological development; AIML is consistently ranked in the top 10 organisations for computer vision research in the world. Precision healthcare solutions to wicked health problems, empowered by AI, hold enormous promise but are critically reliant on the availability of 'big data' - extensive population-based longitudinal data linked to large biospecimen collections. To meet this challenge, we are working closely with the Government of SA to create a state-wide data platform to make best use of our unique and extensive population data resources. This will cement Adelaide's reputation as a leading international light in medical AI research and translation. Apart from the obvious benefits to the health of the SA population and the economic benefits from developing a strong local biotechnology industry, this also means that our children will no longer feel compelled to go elsewhere to work in cutting edge technological areas. As the 3rd industrial revolution continues to dramatically change all aspects of our life, we can look forward to a bright and prosperous future for medical AI in SA.

Artificial Intelligence for Disease Diagnosis - The Future of Medical Imaging

Words by Caleb Tang (Year 11)

Thought starters

Increasingly capable hardware, faster computer processing speeds, more widely available data, and greater global interconnectedness over the last decade have enabled for the rapid development of AI tools and technology which are becoming ever more pervasive in our daily lives. Particularly in recent years, the integration of artificial intelligence into medical imaging has ushered in a transformative era in the field of disease diagnosis, allowing for more accurate, efficient, and timely detection of a multitude of medical conditions. As such, the synergistic relationship between natural intelligence and artificial intelligence is becoming more and more prominent, and the implications of their convergence in an ever-evolving medical landscape will undoubtedly shape the future of modern medicine and disease diagnosis.

Currently, artificial intelligence is most impactful in visually oriented specialties such as dermatology, whereby specially developed clinical imaging datasets and neural networks are increasingly being used to aid physicians in the diagnosis of skin cancer, skin lesions, and psoriasis. Most notably, the use of a binary classification machine learning model in 2020 to classify images into one of two categories; either keratinocyte carcinoma or seborrheic keratosis; and malignant melanoma or benign nevus (see Figure 1), achieved a performance rate equivalent to that of 21 board-certified dermatologists. Trained using just 129,450 images similar to those taken with a mobile phone, in a deep convolutional neural network (DCNN) model, this research has highlighted the capability of AI systems in classifying skin cancers to a high degree of accuracy at relatively low cost.

In addition to patient diagnosis and disease identification, major advancements by researchers at Google have led to the training and development of a DCNN model for use by ophthalmologists to classify images as either diabetic retinopathy or macular edema (see Figure 2) for adults with diabetes to also improve the efficacy of patient prognosis. This allows for earlier detection of diabetic retinopathy due to the ability of the DCNN model to study images at a granular level, which is currently impossible for a human ophthalmologist to do, while being able to grade the degree of diabetic retinopathy and provide ophthalmologists with a second opinion, leading to increased diagnostic efficiency.

The primary benefits of artificial intelligence algorithms in medical imaging involve the speed and quantity of images, e.g. X-rays, MRIs, ultrasounds, CT scans, and DXAs, and patient data, e.g. medical 2D/3D imaging, bio-signals (e.g., ECG, EEG, EMG, and EHR), vital signs (e.g., body temperature, pulse rate, respiration rate, and blood pressure), demographic information, medical history, and laboratory test results, which can be analysed. By enabling the rapid integration of multiple data sources into diagnostic decisions, artificial intelligence allows clinicians to gain a more comprehensive understanding of patient health in a shorter amount of time, allowing for more accurate predictions and more informed decisions. The multimodal data which can be more efficiently analysed by artificial intelligence also provides a more complete picture of patient health and the underlying causes of their symptoms, allowing clinicians to better monitor the progression of a condition over time, which is particularly beneficial in the treatment and management of long-term chronic diseases.

The future of AI-based medical diagnostics will be characterized by continued growth and development. More advanced AI technologies are being introduced into research domains and healthcare facilities every day, with quantum AI being at the forefront of AI innovations to speed up the conventional lengthy training process required for DCNN

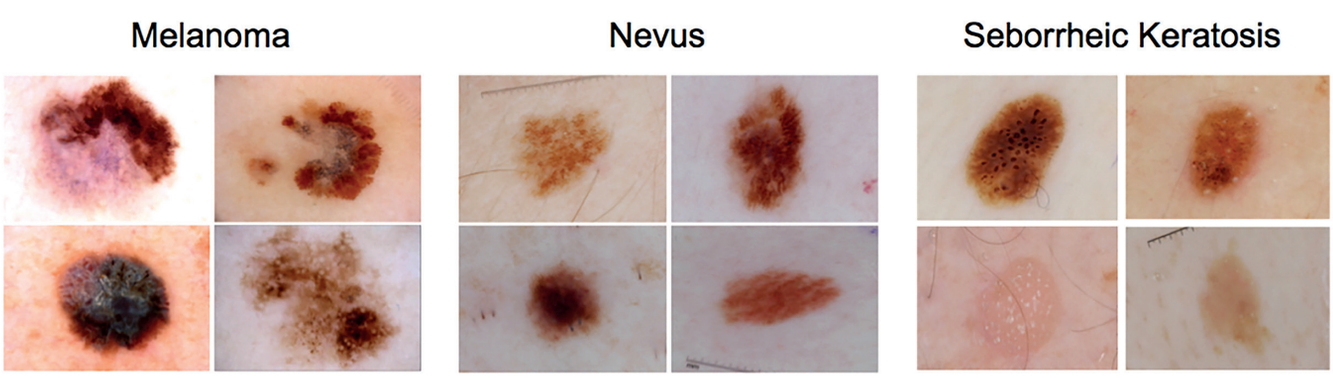

Figure 1: Comparison of melanoma, nevus and seborrheic keratosis

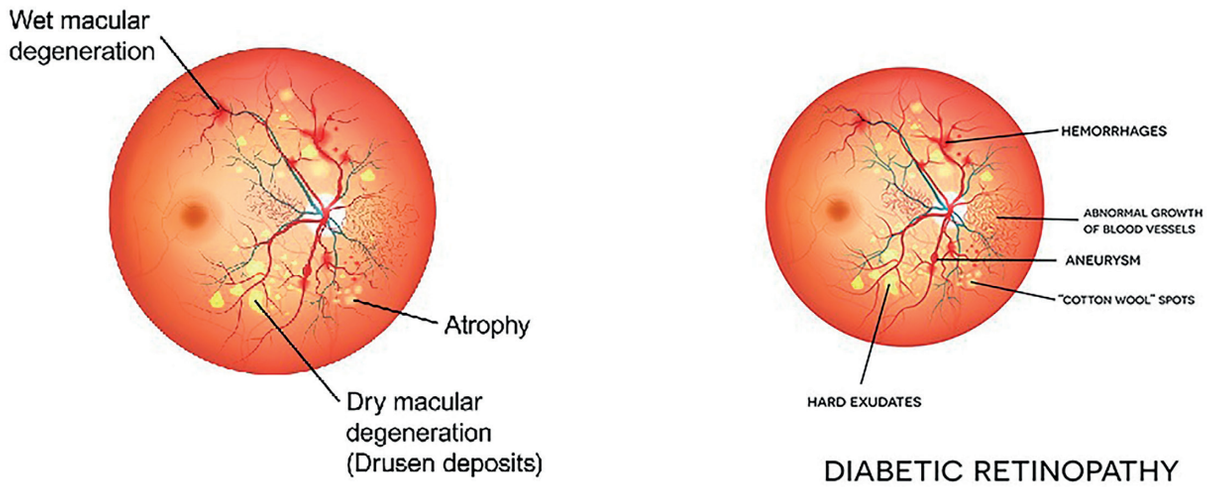

Figure 2: Comparison of macular degeneration to diabetic retinopathy

machine learning models. The increased processing power of Quantum computers, paired with more optimised decision-making processes and enhanced identification of patterns and relationships, will allow artificial intelligence to generate more long-term patient treatment plans based on a variety of factors such as their medical history, lifestyle and genealogy. In the near future, AI medical services will be extended to more rural regions as well to increase the availability of healthcare, particularly patient diagnosis, in remote areas.

However, the development and deployment of AI in medical diagnostics are still in their early stages, with several technical, regulatory, and ethical challenges yet to be overcome. AI algorithms typically require large amounts of high-quality labelled data to be effective, which is not only time-consuming to create, but the limited data available is also often fragmented, incomplete, unlabelled, and/or unavailable. This is particularly evident in the medical field, where issues of patient privacy are becoming increasingly controversial due to recent incidents of data breaches by major corporations. Technology such as facial recognition and gene analysis means that a single individual can often be identified relatively easily from a pool of even millions of people, leading to a reduced willingness of patients to share their personal health data, and hence a restricted availability of data for medical machine learning to train artificial intelligence models with.

Another limitation of the application of AI is that models designed and deployed for a specific task cannot be seamlessly transitioned for immediate use to another organization without substantial recalibration. Due to privacy concerns, data sharing is often inaccessible or limited between healthcare organizations, resulting in incomplete data which limits the reliability of the artificial intelligence. The complexity of the mathematical and scientific algorithms involved exacerbates this inaccessibility to data. Furthermore, the process of creating AI algorithms is often heavily biased due to targeting a particular race, gender, age group, etc., and can lead to incorrect and unfair diagnoses if trained on data that is not representative of the population they are intended to serve.

Ultimately, despite its limitations, the use of artificial intelligence in medical imaging holds immense promise for revolutionising the accuracy, efficiency and accessibility of disease diagnosis. From early detection of anomalies to the differentiation of subtle tissue characteristics, artificial intelligence has demonstrated its potential to enhance the diagnostic process across various modalities, including radiology, dermatology and ophthalmology. However, as intelligence, both human and artificial, continues to evolve, the maintenance of robust regulatory frameworks and ethical considerations will be crucial in ensuring the safety and reliability of these technologies, particularly surrounding patient privacy and bias mitigation in the introduction of artificial intelligence into clinical practice.

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Coming to a pharmacy near you

Words by Davesh Anavkar (Year 8)

Thought starters

Would an accountant do the same job as an engineer? Probably not. So why does medication have to function the same way? If you had an easily curable disease, but could not receive the treatment necessary to save you, because you had an allergy to the medication, how would you feel? These are three questions that come together to form the answer. The bliss of personalisation in medicine, may come in the form of personalised medication, sometime very soon.

Personalised Medication (PM), also known as personalised medicine or precision medicine, refers to an approach in healthcare that tailors medical treatments and interventions to individual patients based on their specific characteristics. It takes into account various factors such as a person's genetic makeup, lifestyle, environment, and other relevant data to provide customised treatment plans.

Personalised medication works by collecting and analysing data about an individual's unique characteristics, such as their genetic makeup and medical history. This information is used to tailor treatment plans specifically to the individual, considering factors that may influence treatment response. By selecting treatments based on personalised data, PM aims to improve treatment effectiveness and minimise adverse effects. Ongoing monitoring and evaluation help refine the treatment approach for better patient outcomes.

So why do we need PM? Firstly, it allows therapies to be targeted that focus on specific molecular or genetic characteristics of a disease. This approach can lead to more precise and effective treatments, especially in the case of complex and difficult-to-treat conditions like cancer. Personalised medicine considers factors that affect drug metabolism, such as genetic variations in drug- metabolising enzymes. By understanding an individual's ability to process medications, healthcare providers can determine the optimal dosage for maximum effectiveness and minimal side effects.

Some medications may cause adverse reactions or side effects in certain individuals due to their genetic predisposition. Personalised medicine can help identify patients who are at higher risk of adverse reactions, allowing for safer treatment options or alternative medications. With PM, individuals may receive genetic testing and risk assessments to identify their susceptibility to certain diseases. This information can be used to implement preventive measures and lifestyle changes to reduce the risk of developing these conditions. Personalised medicine can improve the management of chronic conditions by tailoring treatment plans to each patient's unique needs and responses. This approach can lead to better disease control and improved quality of life.

While PM may involve upfront costs for genetic testing and analysis, it has the potential to reduce healthcare expenses in the long run by avoiding unnecessary treatments, adverse reactions, and hospitalisations. Not all patients respond the same way to a particular medication or treatment. Personalised medicine takes into account an individual's unique genetic makeup, lifestyle, and environmental factors, allowing for treatments that are more likely to be effective for that specific patient. It can also revolutionise drug development by identifying specific patient subgroups that are most likely to benefit from a new medication during clinical trials. This can lead to faster drug approvals and more targeted therapies.

Personalised medicine also involves patients in their healthcare decisions and treatment plans. By understanding their genetic

Figure 1- Blood samples being tested.

predispositions and risks, patients can make more informed choices about their health and participate actively in managing their conditions.

So when could we receive the capability for PM's production? Are there any barriers in place?

Well, PM relies heavily relies on understanding an individual's genetic makeup. As advancements in genomics and technology continue, the ability to analyse and interpret genetic information becomes more accessible and cost-effective.

The production of PM will require regulatory approval and adherence to guidelines to ensure safety and efficacy. The development and implementation of these regulations may influence the pace at which personalised medications are produced and adopted.

The availability of resources, healthcare infrastructure, and investment in research and development play a significant role in the capacity to produce PM. Developed countries with robust healthcare systems are likely to have more advanced capabilities in this regard.

Collaboration among researchers, pharmaceutical companies, healthcare providers, and regulatory bodies is essential for advancing personalised medicine. Sharing data and knowledge can accelerate progress and the capacity to produce personalised medications.

Rigorous clinical trials and evidence generation are necessary to establish the safety and efficacy of personalised medications. These will take time. The availability of sufficient clinical data supports the adoption and scale of PM approaches.

Public awareness and acceptance of personalised medicine can influence its adoption. Educating patients and healthcare professionals about the benefits and potential of PM will need to occur and is crucial for its widespread use and acceptance.

Finally, as PM involves genetic information and individual data, addressing ethical and privacy concerns is essential for building public trust and ensuring responsible implementation.

Personalised medicine relies heavily on the collection and use of data. The Walter and Eliza Hall Institute of Medical Research (WEHI) has been bravely scratching the surface of PM, collecting sets of data from a wide range of people. This data has related to the following:

Other than the work conducted by the WEHI, other research firms are utilising a process that includes the following steps:

The first step in producing PM is to gather genetic information from the patient through genetic testing. This may involve collecting a sample of blood (Figure 1), saliva, or tissue to analyse the patient's DNA. Such testing can identify specific genetic variations and mutations that may influence drug responses or disease susceptibility.

Once the genetic data is collected, it needs to be interpreted and analysed. This involves identifying relevant genetic variations and understanding how they might impact the patient's ability to metabolise medications or respond to specific treatments.

Based on the genetic analysis, healthcare professionals can then choose medications that are more likely to be effective for the individual patient. They can also identify targeted therapies that focus on specific molecular or genetic characteristics of the disease.

Genetic information can also help determine the optimal dosage necessary for the patient. Some genetic variations can affect how the body processes drugs, and the dosage may need to be adjusted accordingly to ensure safety and efficacy.

Once the specific drug and dosage have been determined, personalised medication can be manufactured or formulated to meet the individual patient's needs. This might involve customising the drug's formulation or adjusting the drug's concentration.

Personalised medication can be delivered through various methods, depending on the drug and the patient's preferences or medical requirements. This could include oral medications, injectables, transdermal patches, or other specialised delivery systems.

Like any medication, personalised drugs must go through rigorous quality control measures to ensure safety, efficacy, and consistency in production. This step is critical to maintain high standards and prevent any adverse effects.

After the PM is prescribed, healthcare professionals will closely monitor the patient's response and adjust the treatment as needed. Regular follow-ups and evaluation are essential to assess the effectiveness of the personalised approach.

So the field of PM has significant potential to transform the diagnosis and treatment of disease. However, certain testing and data collection issues must be closely monitored to ensure it is ethical and its benefits maximised.

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Is there legitimate scientific benefit to brain training/brain games?

Words by Hugo Shaw (Year 9)

Thought starters

"Brain games" are programs which claim to help people improve and strengthen their memory by forcing them to solve puzzles. Brain games are easily accessible to the public, making them extremely popular. Due to the raising awareness of mental conditions such as dementia and an ageing population, these games have increased significantly in popularity. Over 55 million people suffer from dementia globally, thus creating demand for brain training programs. People often lose memory from a process known as demyelination, where myelin sheaths (a protective layer around neurons) are lost.

Memory is the action of recalling stored information, through the reactivation of a group of neurons specific to that piece of information. The myelin sheath is a protective, fatty layer which helps to recall information faster (Figure 1). When the myelin sheath has deteriorated, nerve impulses may be slower or stop entirely. This often leads to difficulty remembering certain pieces or information or forgetting that information entirely. When a certain neuron path isn't moved often, the path usually is "pruned" off for being irrelevant.

So who might benefit from brain games? Based on the claims that brain games present, the Elderly, whose myelin sheaths may have deteriorated over time, those with brain injuries, whose repeated injuries may have damaged their neurons and also students who frequently have to rely on their memory during exams/tests, would all benefit from these games.

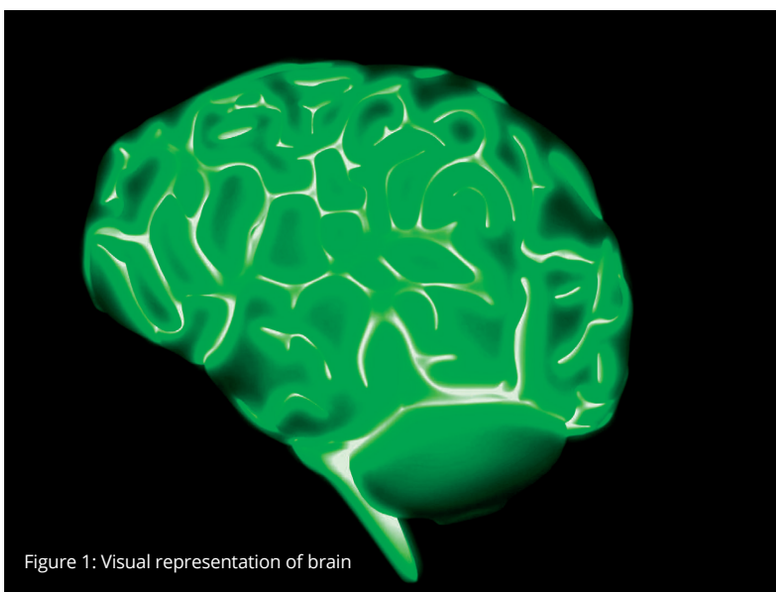

Figure 1: Visual representation of brain

The question is, do brain games actually work? There has been extensive research performed on the effectiveness and impacts of brain games. Despite the fact that some claim that memory-based sections of games activate the hippocampus (vital for recalling information), various studies have found that brain games have little to no effect of preventing or slowing memory loss. Researchers from the University of Pennsylvania conducted a study to determine this. Their study, involving 128 adults, ultimately concluded that brain games do not have any conceivable benefit other than improving the skills specific to that game.

In addition to this study, there are other potential issues related to the use of these games.

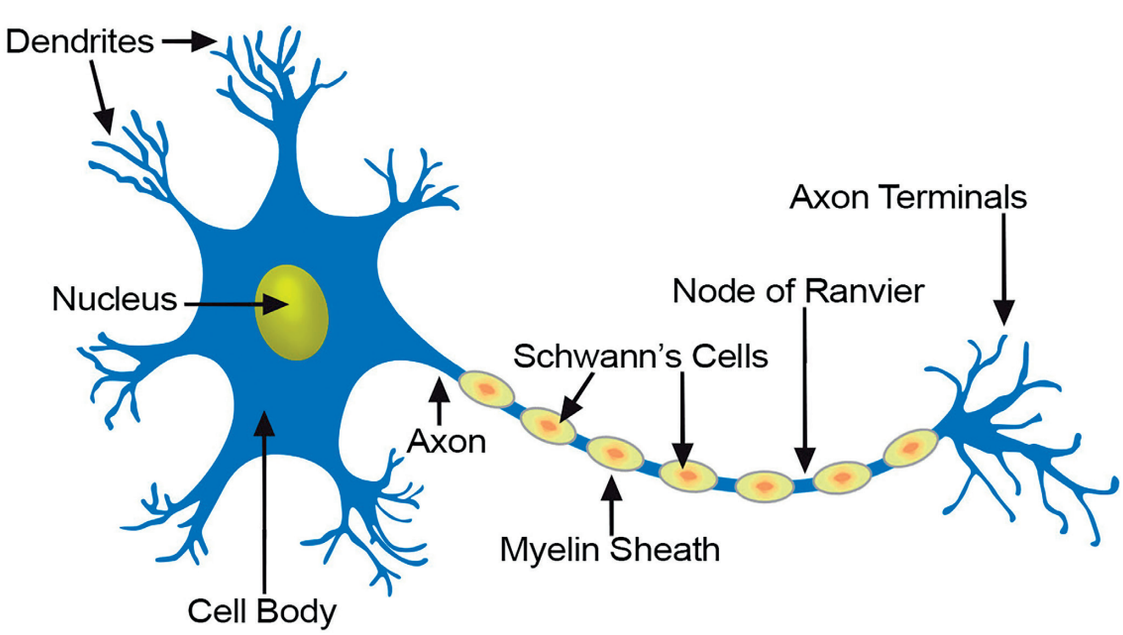

Figure 2 Diagram of a myelinated neuron

They are highly popular and addictive, thus encouraging social isolation. They can also encourage financial disparity amongst society as many games are not budget-friendly to people of lower economic status. These games are sometimes accused of being deceitful. Many of their claims haven't been supported, and the games may be taking advantage of the elderly's fear of memory loss.

Figure 3 Luminosity logo

Many games lock features behind paywalls, and many microtransactions are featured in these games. For example, the company Luminosity has a paid membership, as it gives access to a limited number of games and features on Luminosity. It is a lucrative industry, as which generating $6 billion in 2020.

The brain training/game industry is loosely regulated by the government and companies are rarely ever held accountable for their claims. The previously mentioned company Luminosity was ordered to pay over $2 million for falsely advertising the benefits of its program, stating it would "Protect Against Cognitive Decline".

Given the extensive research performed on this topic, including the aforementioned University of Pennsylvania study, it seems that brain games have little to no tangible benefits, and are thus ineffective at preventing or stopping memory loss. For the future, as technology is ever-evolving, perhaps new brain training programs could be developed which have strong evidence supporting their claims which could benefit society. But as it currently stands, it seems that brain training needs more research performed to prove its effectiveness.

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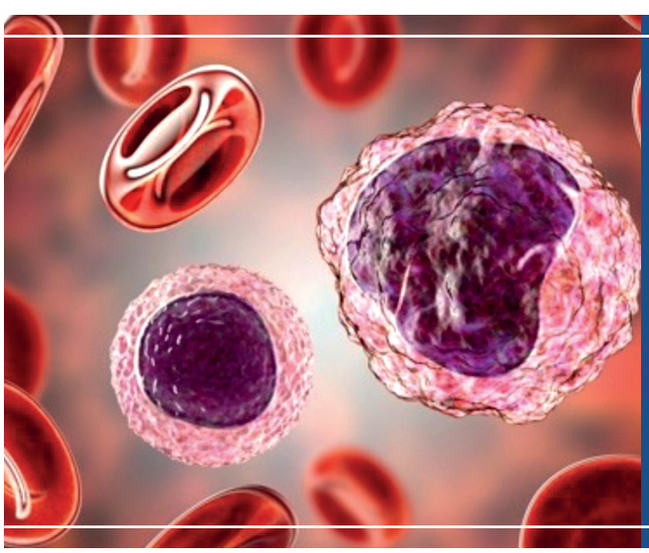

Ten per cent of your body mass is made up of your blood. As such, your body has enough iron to make a three-inch-long nail.

How can diet affect intelligence?

Words by Lachlan Logan (Year 7)

Thought starters

You may not know it, but what you eat can affect your intelligence. Having a diet with too much sugar and fat can result in a lower IQ but a diet full of nutrients, fruit, vegetables, and omega - 3 fatty acids can result in you having a higher IQ. Healthy diets benefit our brain functions in many ways, but unhealthy diets have a negative impact on our cognitive abilities.

If you are wondering how you can boost your intelligence by what you eat, it is all about your childhood. Children who regularly ate fish, vegetables, and healthy carbohydrates had a strong correlation with high IQ scores. Children who had a diet rich with processed foods, fats, and sugars had a strong link with low IQ scores. It is very important to eat healthy foods in your childhood. Also, blood sugar levels need to be controlled. Abnormal blood sugar levels are associated with low IQ scores.

What we eat affects the synaptic plasticity of our brains. This is a measure of the connections between neurons - the more connections, the greater our cognitive abilities. A healthy diet can lead to more connections between neurons meaning we can think faster.

Neurogenesis is the process where the brain produces new brain cells. A healthy diet rich with nutrients boosts the production of new brain cells but a diet full of fat and sugars can cause inflammation and slow neurogenesis in the brain. Neurogenesis improves learning, memory, mood, attention, and general health.

Neurons, especially those in the hippocampus, produce and use molecules to send and receive messages (see figure 1). One of those molecules is brain derived neurotrophic factor (BDNF). BDNF protects neurons from death, increases neurogenesis, and improves our thinking. A healthy diet can increase levels of BDNF.

An unhealthy diet has many negative effects on the brain, causing inflammation and can make it harder to concentrate, remember and plan. It can also cause your body to release too much of a stress hormone that can activate the brain's microglia and astrocytes at times when they should not be active.

You may not know it but, the brain and the gut are connected by neurons that transmit messages between them. The food we eat is sensed by the neurons of the gut and which then alert the brain. This is called the gut brain axis. Because of the gut brain axis an unhealthy diet can cause problems with our cognitive functions.

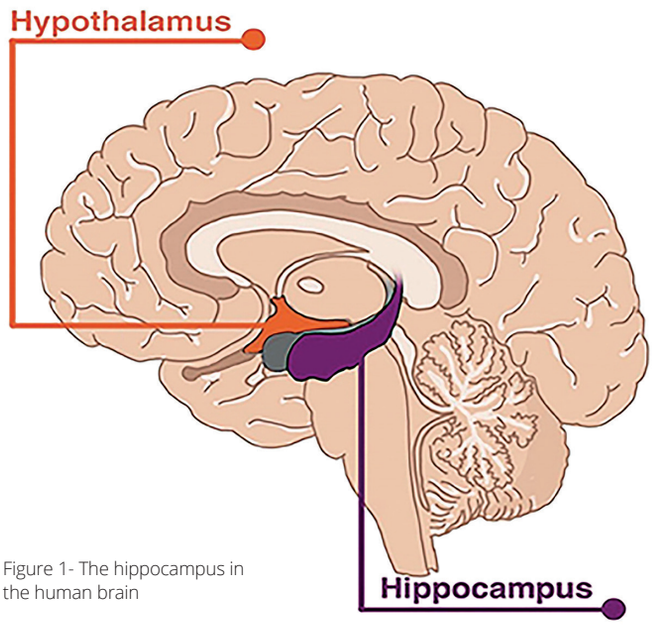

Figure 1- The hippocampus in the human brain

It is very important to know what not to eat when it comes to your brain health. We need to stay away from sugars and fats, but the worst thing for your brain is artificial sweeteners. One artificial sweetener, aspartame, is present in diet drinks and makes you irritable, anxious and can cause sleep disturbances. A high fat diet is also very unhealthy because it can lead to oxidative stress in the brain. This is a harmful process that can disrupt several structures inside cells. A high fat diet can also activate the microglia at times when it should not be active which can lead to inflammation in the hippocampus and the hypothalamus. The hypothalamus is responsible for the body's body weight control. Inflammation in this part of the brain can make a person eat even more. Artificial foods, like trans fats

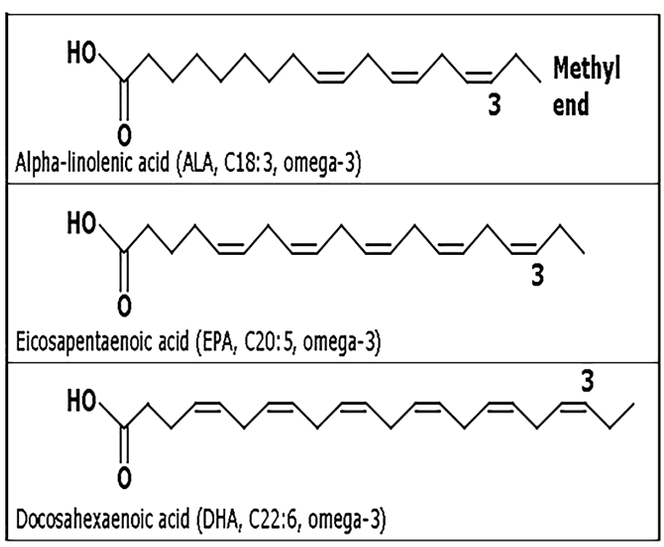

Figure 2- Molecular structure of ALA, EPA and DHA

Figure 3 Sources of omega 3 fatty acids

are very bad for you - the worst type of fat to eat. They increase the risk of anxiety and Alzheimer's disease. They are found in frostings, snacks, store-bought cookies and cakes.

The best thing for your brain that you can eat are omega-3 fatty acids. They can improve brain function and decrease the risk of brain disease. If we do not eat enough of them, inflammation can take place on the brain. Omega-3 fatty acids are an essential nutrient, which means we must obtain them through our diet because our bodies cannot produce them. There are 3 main fatty acids in this group. A-linolenic acid (ALA), which is found in plants and edible seeds, eicosapentaenoic acid (EPA) and docosahexaenoic (DHA), which are both found in fish oils (see figure 2). A diet full of fish oil, seeds, and nutrients is the best you can do for your brain and hopefully it will increase your IQ. (Figure 3)

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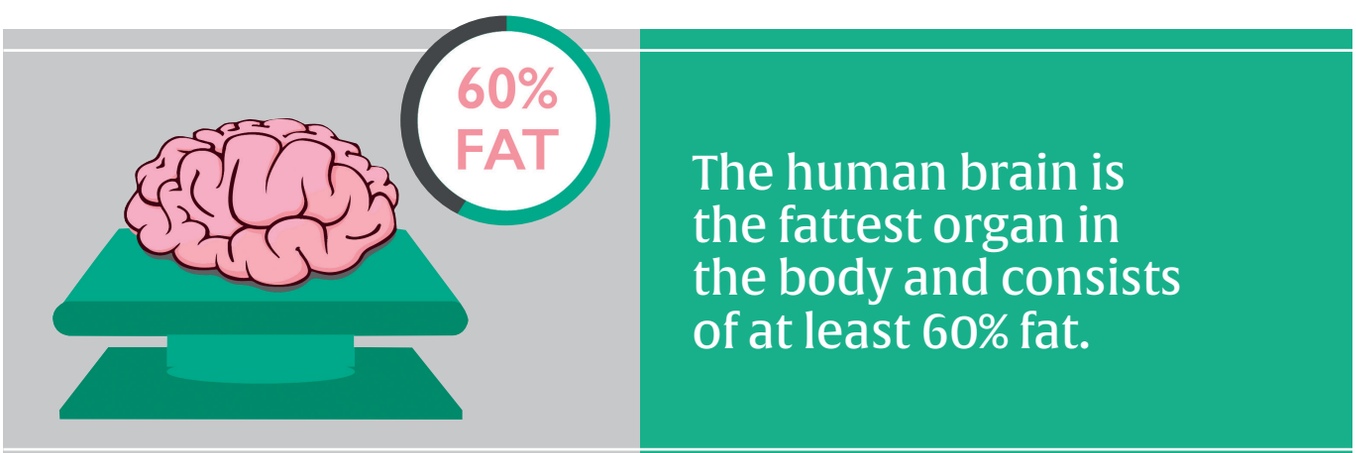

Building trust with artificial intelligence for the sake of Humanity

Words by Lachlan McKay (Year 11)

Thought starters

The James Webb Space Telescope (JWST) has been popular in the media since its launch on Christmas 2021, and again in July 2022, when the first images were released to the public, demonstrating to the world the power of its ground-breaking technology. The telescope gave scientists around the world access to vital information and specific data regarding the universe and allowed them to reverse-engineer aspects of the Big Bang. Furthermore, the general public were also provided with beautiful images of galaxies, nebulas, and stars much larger than any of us can comprehend.

Interestingly, the raw images taken by the telescope weren't the images released, in fact, the true images are mainly just black. Whilst this may sound like the images released were forged just to make them look pretty, but instead, it is because the JWST captures the images in infrared, a type of light invisible to the human eye. To adjust for this, data analysts use a group of images and data recorded within specific angles, and use artificial intelligence to create a final image that is visible to the human eye, yet also accurate when compared with what the telescope originally recorded through infrared.

Aside from being an interesting fact, it also outlines an important potential relationship between artificial intelligence and human intelligence. Humans are undoubtedly intelligent, but suffer from any number of limitations, such as our eyes being unable to see infrared. Luckily, we have the capacity to create technology that builds on our limitations, turning them into our strengths. There are large parts of the universe which we would have no understanding of if it weren't for technology allowing us to see it in more detail.

AI's are made by giving a machine a task and essentially generating a near infinite amount of combinations, which AI then re-orders until there are some successful combinations. Some will fail, whereas others will succeed, and using a sorting algorithm, those that failed are removed and, those which were successful are used as the new benchmark. A sort of artificial natural selection. The dilemma that AI provides is that, due to the complexities of creating an AI, it is hard for people to understand, and therefore it scares them. Unlike other technologies that humans have developed and know every detail about it and how and why it functions, AI's actually build themselves with only guidance from humans meaning we will not know exactly how it works, we will only know if it does work, and this can be scary to some people.

This means Humanity will be entering a new age when it comes to technology. We will be making rapid advancements efficiently and effectively but we will not understand how we got there, meaning that humans will have to put a large amount of trust in artificial intelligence. Whilst we may not be able to check if its right, we must place trust in the humans which created it. Ultimately, life could become like the images of the James Webb Space Telescope; mostly black and impossible for humans to understand, until an AI can translate it for us, make it perceivable to us, and we will have to trust that what they are showing us is the truth.

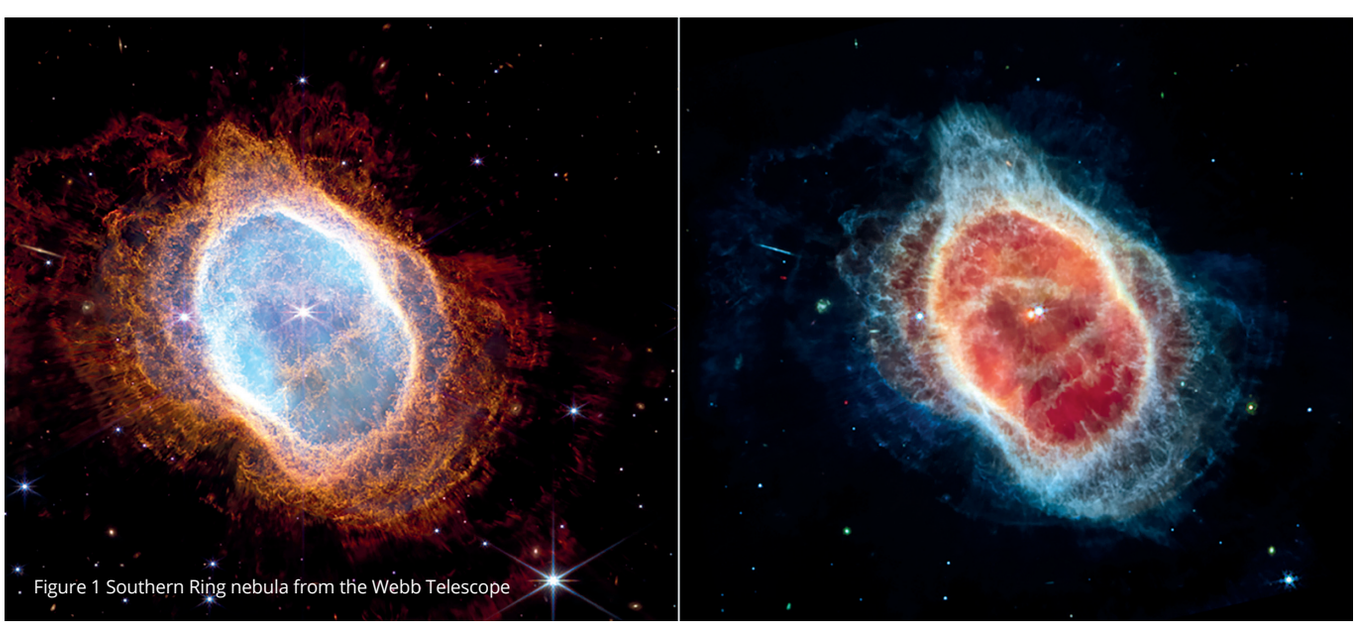

Figure 1 Southern Ring nebula from the Webb Telescope

The Alignment Problem

Words by Max Thomas (Year 12)

Thought starters

In 2016, Microsoft released a chatbot called 'Tay', an automated Twitter bot that was programmed to imitate the thoughts of an average 19-year-old American girl. Bots had existed on Discord servers, Twitter feeds, and Reddit channels for years. However, Tay had something unique: it could read other tweets, incorporate data analytics into its programming model to see what content became popular, and adjust what it said accordingly. It didn't take long for this to get out of hand. Before Microsoft took down the bot, it began to spill racist vitriol over the internet, and in one viral tweet, argued, "Bush did 9/11 and Hitler would have done a better job than the monkey we have now. Donald trump is the only hope we've got." Humanity's fear of a machine going rogue – so to speak – has existed for a long time and has been a recurring theme in dystopian fiction. Samuel Butler's 1872 Victorian satire Erewhon explored the idea of a self-replicating, conscious machine. In 2001: A Space Odyssey, HAL 9000 malfunctioned and killed the entire crew except the commander. Perhaps we'd like to think of artificial intelligence as more sympathetic to humanity's goals, say R2D2 in Star Wars. However, this development or 'alignment' as it is referred to in computer science will not just happen; it is incumbent on developers and policy writers to ensure we have an adequate framework that allows for the safe new development of this technology. Allow me first to explain a brief history of how we got to Tay saying the things it did.

In 1950, the mathematician (perhaps a reductive career definition given he was a polymath) Alan Turing published a now infamous paper titled Computing Machinery and Intelligence, which sought to answer the question: "Can machines think?" This was more of a question of epistemology than computer science, but he still had a crack: Turing came to the conclusion that this was an unsatisfactory question because 'machine' and 'think' are undefinable. Instead, he argued, if it behaves like a human, it can probably be treated as though it 'thinks', whatever that might mean. And with this thesis, the Turing Test was born, which he initially called The Imitation Game: A machine could think if it could fool a human into believing it was human. This can be tested quite simply: consider a room separating an interviewer from two interview subjects sitting behind a screen. If the blind interviewer asks a series of questions to be responded to and cannot tell which answers were written by a human, the machine is intelligent. The first machine program, considered to be a piece of AI, was written in 1956 called Logic Theorist. At the Dartmouth Summer Research Project on Artificial Intelligence conference, which brought together the leading minds in the field, proofs of 38 of the 52 in Whitehead and Russell's Principia Mathematica were solved by the machine, some supposedly more eloquent than the initial proofs in the book (yet far beyond this writer's lacking mathematical competency to understand). And so, they did it. But this conference had a bigger plan: build a computer that would not be programmed for a single mundane operation (i.e., perform mathematical calculations) but to form 'general intelligence'; that is, give the machine some starting stimulus, provide it with the language so it can learn whatever it wants, and watch what happens. The idea of self-teaching machines that respond to stimuli and adapt accordingly has come a long way since that summer in New Hampshire. Despite being beaten in the first match, IBM's Deep Blue computer beat world chess champion Garry Kasparov in 1997. In 2019, Project Debater came up against World Universities Debating Championship winner Harish Natarajan (the robot was beaten, but alas, it was an impressive performance). More recently, OpenAI has made ChatGPT publicly available, which has brought an AI chatbot to the masses for the first time.

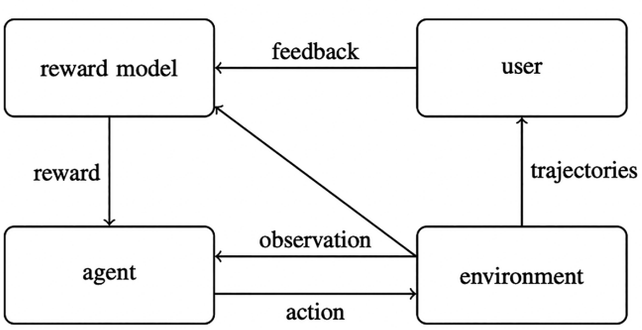

Figure 1: The recursive reward model

All of these programs have been given 'terminal goals' by their developers. This represents an end-goal of the software: checkmate your opponent, convince a logical and reasonable person that you are correct, or provide a well-reasoned answer to a human prompt. AI programs achieve terminal goals through 'instrumental goals': if you open with the e4 pawn and your opponent plays e5, you will statistically maximise your chances of victory if you move your knight to f3 (admittedly this depends on the opponent and your strengths as a player, but as a general rule this holds). You need to provide more convincing reasons than your opponent and win the theme of economics in the round. Instrumental goals represent smaller steps than an artificial intelligence bot will take in order to achieve the terminal goal. The alignment issue occurs when either 1) the bot is given (or develops its own) dangerous terminal goal, say to destroy humanity, or 2) the instrumental goals the bot outlines for itself are a dangerous way to achieve the terminal goal. The first issue is the one popularised in science fiction: an evil bot with human-like tendencies that wants to destroy humanity. It seems like a bit of a stretch to me as it currently stands. The second goal is a far more pertinent issue. Let's say you gave intelligence the terminal goal of making the PAC Science Journal the most renowned publication in academia. It could presumably do this in a number of ways. First, it could reject all student submissions and pay world-renowned scientists to write for the publication, rivalling the author pool of Nature, The New

England Journal of Medicine, Science and other journals. Or, second, destroy every other scientific journal that exists and kill all other scientific publishers apart from Mr. Hopkins, so PAC's publication becomes the best by default. This represents an instrumental goal (blood and death) in pursuit of the terminal goal (the prestige of the science journal). Thus, developers must program their bots to align human values to their algorithms in the operation of instrumental goals. This invites the question of the so-called 'Alignment Problem': How can we create agents that behave in accordance with the user's intentions.

One solution proposed is the adoption of recursive reward modelling. You can think of this like you would train a dog: if your German Shepherd sits down on command, rolls over, and shakes your hand, you treat it. In a paper published by Google DeepMind, some researchers published a basic illustration of how this works (see Figure 1):

This model is predicated on the assumption that the person controlling the machine can recognise when the bot does something aligned with humanity's interests. However, particularly intelligent programs can avoid this model through something called reward hacking (also referred to as specification gaming). This is where the machine achieves the program's specifications but does not achieve the creator's goal (often due to poorly explained commands). In a human game, we'd refer to this as cheating. Consider a simple example of reward hacking explained by Google DeepMind. You tell the AI to place a red Lego brick higher than a blue one (see Figure 2). What the developer is really asking is for the bot to stack the red piece on top of the blue one (the terminal goal), but a misaligned machine could simply flip over the red brick, so it's technically higher than the blue one (see Figure 3).

This is a trivial example, but, like any scientific development of significance, there are other potentially dangerous applications. The more complex an AI program becomes, the harder it is to maintain scalable oversight of that technology. This is for the simple reason that deep learning programs can develop languages that computer scientists do not yet understand.

Alignment has recently become a key priority in existential risk research – to create safe frameworks for development or avoid the technology falling into the wrong hands (e.g., for defence or bioweapons development). Earlier this year, leading academics, CEOs, researchers, and computer scientists came together to sign a letter arguing that "Mitigating the risk of extinction from AI should be a global priority alongside other societal-scale risks such as pandemics and nuclear war." The signs for global cooperation on this issue are promising. UK Prime Minister Rishi Sunak has recently announced the first Global AI Safety Summit to be held in November 2023, where leading researchers intend to discuss risk-based AI rules. In any case, the rapid pace of development in this field is an exciting one that promises to accelerate medical developments and improve efficiency in many routine tasks. However, we must ensure that Alignment remains front of mind in this new chapter in computer science. To quote Alan Turing, who concluded their 1950 paper on AI with a quote that adorns the door of classroom W010 in the maths building: We can only see a short distance ahead, but we can see plenty there that needs to be done.

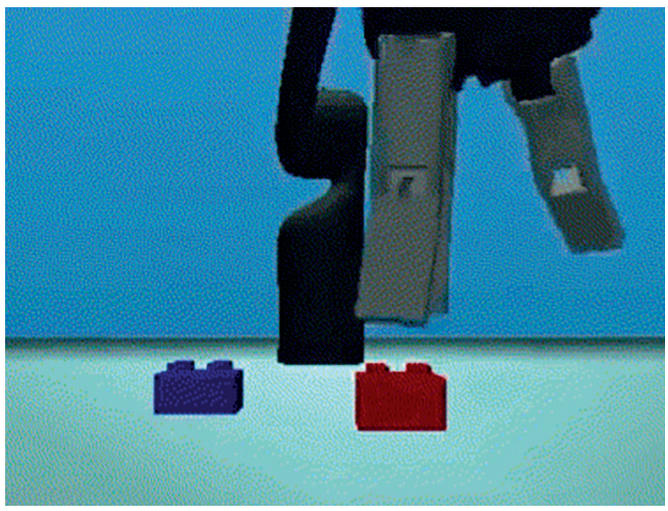

Figure 2: Bot goes to pick up red Lego piece (developer intends for it to be stacked on blue)

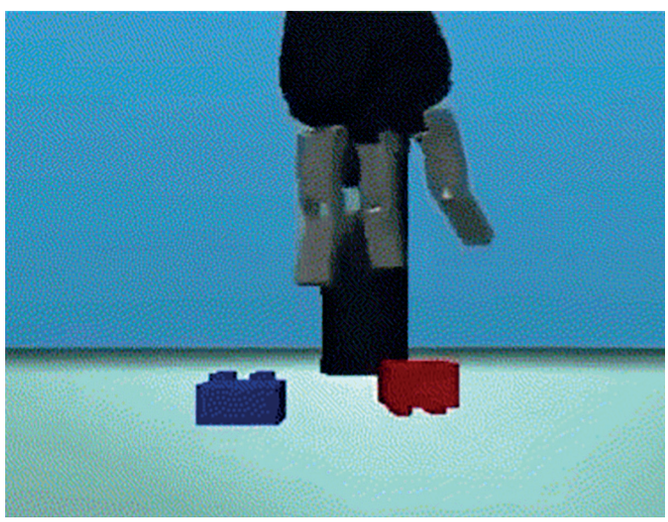

Figure 3: Bot flips over the piece

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Artificial Intelligence and Diabetic Retinopathy Screenings

Words by Michael Cook (Year 11)

Thought starters

Diabetes mellitus is a common chronic, metabolic disease, with 415 million people worldwide living with it. Diabetes causes long-term effects when not regulated that require medical attention. One is diabetic retinopathy, which can lead to a partial loss of vision or blindness without early treatment. Currently, only specialists can diagnose the condition. An artificial intelligence (AI), diabetic retinopathy grader (DR grader), has been created which can analyse retinopathy screenings and make diagnoses. Its application is clear in general practices responsible for referring specialist treatment as it performs diagnoses that ophthalmologists typically perform. There are, however, limitations that must be addressed before adopting AI into general practices. DR grader shows development of the current process of diagnosis as it can evaluate the severity of a patient's retinopathy, increasing the efficiency of the process.

Without diabetes, the body, through a negative feedback loop, naturally maintains a blood glucose level. Insulin is an essential hormone in the loop, which prompts cells to store glucose. Diabetes is when the body does not produce any or enough insulin. This disrupts the natural homeostatic processes and means no hormones can be released to communicate to the liver (or other cells) to store glucose. When diabetes is not managed, frequent high blood glucose levels cause sequelae such as diabetic retinopathy, where high glucose in the bloodstream can damage your retina – the part of your eye that detects light. This leaves patients with vision loss or blindness. Due to the nature of the sequela, there can be a range of severities for the condition which require various levels of medical attention.

AI, generally, is a simulation of human intelligence through code. DR grader is composed of deep learning as well as rule-based machine learning. The deep learning and rule-based algorithms used to develop DR grader were trained through supervised learning, which is learning through training data that has been categorised by humans previously, so the algorithm can be adjusted based on its accuracy to the training data (like a teacher and student). In this case, the AI was given a database of 30,000 retinopathy screenings from the DiaRetDB1, Kaggle and Australian diabetic retinopathy databases. This training dataset allows the rule-based algorithm to determine a binary output of either "disease or no disease" by creating rules for certain recurring features of the image such as microaneurysms and exudates, which influence the chance of diabetic retinopathy. The accuracy of the model is then evaluated by comparing diagnoses by DR grader with ones made by ophthalmologists, where the model can be refined to achieve higher accuracies. The deep learning model is trained simultaneously but is much more complex. Deep learning is convoluted by a network of connected nodes, where each node is its own regression model for specific characteristics and their influence on the chance of diabetic retinopathy. This neural network is similar to the human brain. Each connection between nodes will have a threshold or weighting, which when surpassed activates the next node, essentially, forming an interconnected flow chart. After training, the AI will have formed its understanding of the features of an eye screening that influence the chance of diabetic retinopathy. This loop of refinement increases the accuracy of the AI over time, where DR grader is eventually ready for primary-care implementation.

The current process of diagnosis for diabetic retinopathy is slow. There is currently a 6 week wait when patients are referred to a specialist, and an even longer wait for surgeries possibly needed. A major contributing factor is that several patients referred to specialists do not have diabetic retinopathy, and their screenings delay the diagnosis, and consequently, the treatment which some patients with severe diabetic retinopathy require. Currently, patients undergo dilated eye exams, where a dye is injected into the veins of the patient, which circulates to the eyes and makes any blood vessels that are closed, broken or leaking visible when taking high-resolution photos of the eye. Additionally, optical coherence tomography (OCT) exams provide a cross-section of the retina, indicating leaks of fluid into the retinal tissue. These OCT scans are important in diagnosis, and in monitoring how treatment is working.

DR grader significantly improves the efficiency of the diagnostic process. This was outlined in the deployment of DR grader in a primary care practice in Western Australia by The Australian eHealth Research Centre. Patients who showed signs of diabetic retinopathy underwent a screening which takes around 15 minutes, then, DR grader could diagnose the patient in less than 3 minutes (Figure 1). Essentially, DR grader allows general practices to diagnose diabetic retinopathy without referring patients to an ophthalmologist. As DR grader gives an instant result, those who are diagnosed with diabetic retinopathy can have faster access to treatment and surgeries which will save many patients' eyesight. Moreover, the development of DR grader if set to wider implementation may benefit communities struggling with logistical barriers, cost of visit, or lack of an eye specialist in their community, as this increased efficiency will increase the availability and cost much less than a specialist examination. Ultimately, the increased efficiency of diagnosis with DR grader will allow many people

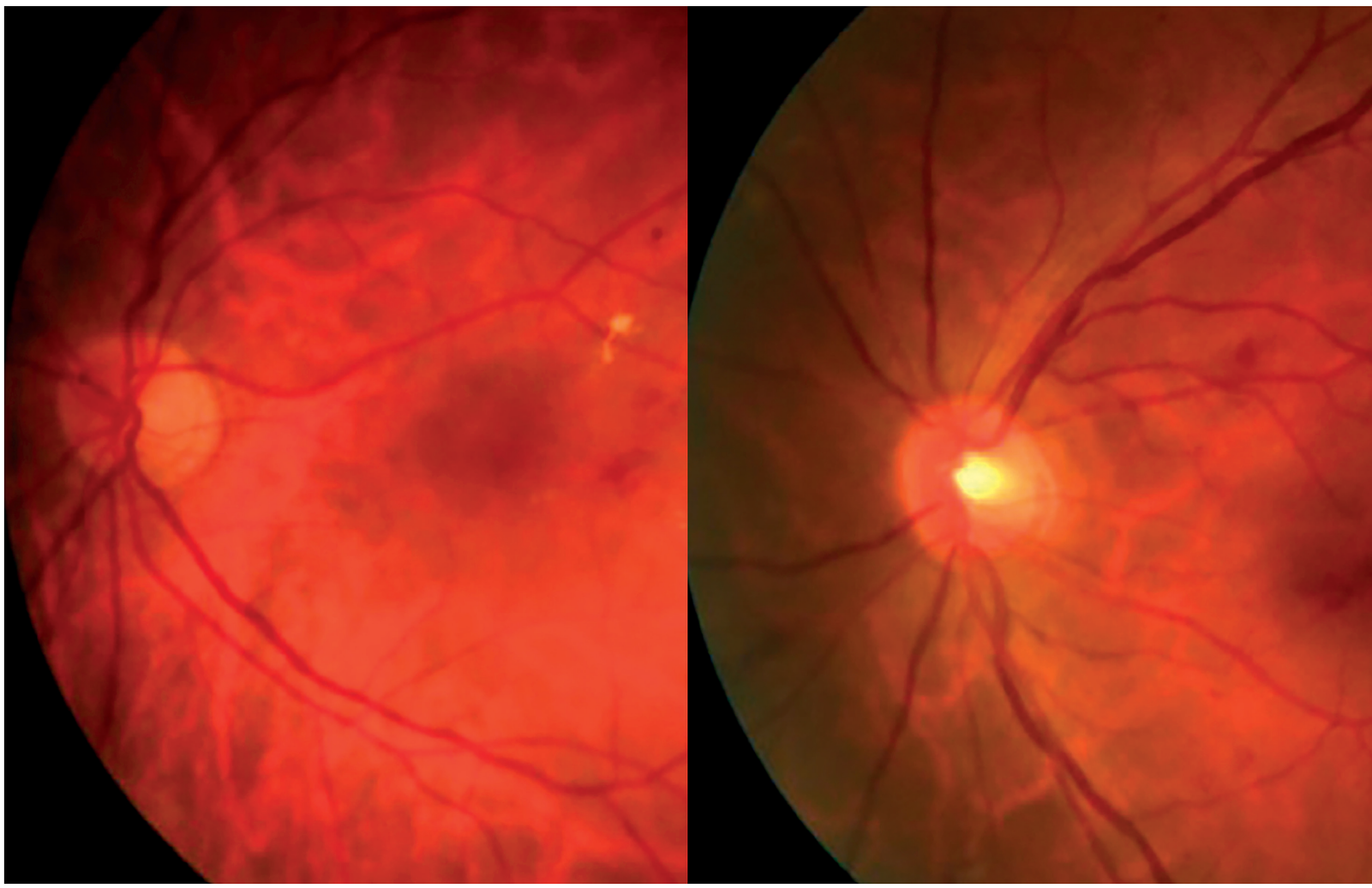

Figure 1: Mild and moderate DR as distinguished by AI

with diabetes to continue living without blindness which would be detrimental to those who already struggle with diabetes.

Despite the efficiency of DR grader in comparison to ophthalmologist referrals, a major limitation of DR grader is the inherent unpredictability of AI. This was emphasised in the initial application of DR grader in general practice, as there were some unexpected results. Importantly, DR grader was able to correctly identify all cases of diabetic retinopathy, however, there was a high number of false positive "clinically significant disease" readings. This was because some patients had drusen, which are deposits of lipids and proteins within the retina, that looked like exudates. Dirty lenses, uneven light exposure, and reflections on the eye all also contributed to some false positives and highlights how in its application, nurses conducting screenings need further training to reduce the frequency of false positives. Due to this high false positive rate, those who are diagnosed with the disease should be reviewed by an ophthalmologist before a referral is made for treatment. Hence, this limitation brings uncertainty to the diagnoses made by AI and requires monitoring. This proves it somewhat inefficient and would likely invoke public debate if considered for further use, preventing AI from further application currently. The Oxford Martin Institute suggests that 35% of UK jobs could be automated out of existence by AI over the next 10 to 20 years. This makes the wider implementation of AI difficult and may have severe consequences as it could eventually risk ophthalmologists' employment if AI technology is expanded to other applications of diseases of the eye.

Ethical considerations for the patient are also a factor because when a patient is diagnosed, they are likely to want an explanation, and nurses using the DR grader would not always have the required qualifications to understand the result, because the AI gives a binary classification without an explanation. Contrastingly, an ophthalmologist can present the screening and outline the specific microaneurysms, exudates, or other symptoms, which signify diabetic retinopathy and give reassurance to the patient and justify the result. Ultimately, the spontaneous nature of AI limits the DR grader system from widespread application.

DR grader, and other AI alike, are improving rapidly, and will likely have much broader applications in the future for ophthalmology. OCT scans, which can monitor the progress of diabetic retinopathy treatment, take up to 43 minutes by humans, but only 2 seconds by AI like DR grader, which will be another significant application of AI technologies within ophthalmology. AI will also predict the benefits and consequences of certain eye treatments for individuals based on their history, images, and clinical genetics, and ultimately be much more accurate with diagnosis of diabetic retinopathy as well as other conditions such as age-related macular

degeneration, which essentially blurs the central vision, and, like diabetic retinopathy, can be detected through dilatated eye-exams. By considering a larger range of factors, dilated eye exams for all diseases may become much more efficient and accurate as AI will consider more factors than a human could.

Ultimately, diabetic retinopathy requires immediate medical attention in severe cases. The current inefficiencies of the screenings must be solved. AI's such as DR grader offer a new solution only possible due to the recent advancements of AI, but when applied will unveil some limitations; most importantly, if the AI can maintain a standard at or above that of a specialist diagnosis. Additional ethical and social issues must be considered including how AI must be further regulated before use and may ultimately automate a specialist's job, leaving them unemployed.

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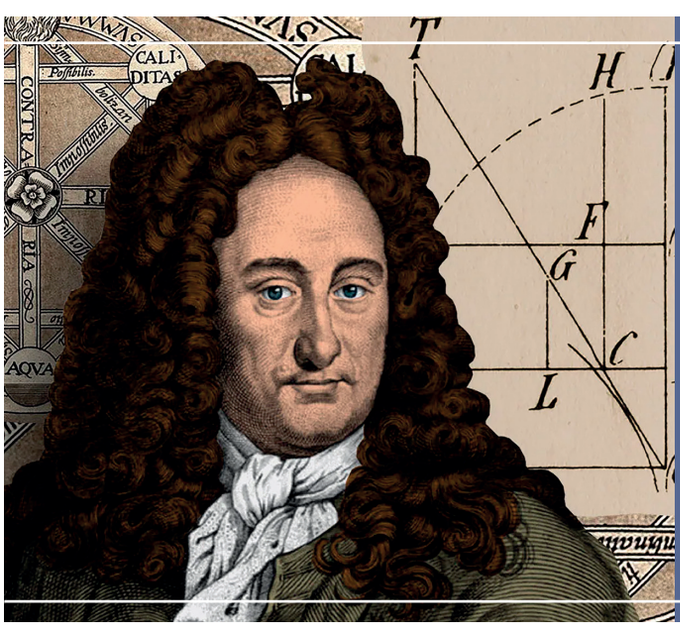

Artificial intelligence was first conceptualized by Gottfried Wilhelm Leibniz, a German mathematician and philosopher, in the late 1600s.

Our Evolving Intelligence - Venoms and Poisons

Words by Noah Laforest (Year 8)

Thought starters

Artificial intelligence or AI is challenging societies view on the concept of intellect. This however is nothing new. Humanity has a long history of making scientific discoveries that have done this. Take venoms and poisons for example. First discovered several thousand years ago, they challenged people's views on plants and animals and the dangers they posed. However, our increased understanding of them allowed intelligence to evolve.

Poisons and venoms are organic compounds (meaning they contain carbon and are derived from living things) and are found throughout the Animalia, Plantae and Fungi kingdoms. In fact, many living things contain some level of toxicity. Before we delve into some examples of each, first a point of clarification. Many people believe that venoms and poisons are one of the same. "Watch out for that snake, its poisonous!" "That snake is venomous"....(Figure 1). Whilst they have similarities, for example, both make you sick or unwell, with effects ranging from mild pain and small scars to organ failure and death, they are in fact different. The key is where they originate from; to put it simply, if you bite it, it is a poison. If it bites you, it is venomous. If you ingest or touch an animal or other organism that contains a toxin, it is considered poison, whereas if the organism bites or stings you, it is considered venom.

Just one more term to tidy up; when the term 'toxin' is used either as a separate word or as a suffix, it refers to any harmful substance produced by an organism, not specifically venom or poison. For example, there are some types of poisons and some types of venoms that both fit under the 'neurotoxin' banner, because they both affect the nervous system.

So let's start with some poisons. Saxitoxin is a potent neurotoxin and one of the well-known shellfish poisons. The term 'saxitoxin' comes from the scientific name of the butter clam (*Saxidomus*), in which it was first discovered in (Figure 2).

It is made up of oxygen, nitrogen, carbon and hydrogen in the chemical formula $C_{10}H_{17}N_7O_4$. Saxitoxin originates from certain species of marine bacteria. Bivalve shellfish (marine molluscs with laterally compressed bodies enclosed by a shell with two hinged parts) such as clams, scallops and mussels feed on bacteria such as this, therefore getting poisoned.

Figure 1 – Venomous or poisonous?

Figure 2 – Butter clams

The poison doesn't affect them much, but it can be bad for humans. Saxitoxin in marine animals has significant impacts on the environment and society. When found in local bivalve shellfish it can cause bans on commercial and recreational shellfish fishing in that area. When saxitoxin is ingested by humans through eating shellfish it can cause paralytic shellfish poisoning (PSP). This is a serious illness that affects the nervous system. Symptoms develop up to two hours after eating infected shellfish and can include numbness, tingling of the lips, and gastrointestinal impairment. The toxin then affects the muscles, stopping them from working properly, causing paralysis. High levels of PSP can cause death.

Ciguatoxin is a neurotoxin and is found in some fish. The term 'ciguatoxin' comes from the Spanish word 'cigua': the name for the gastropod Cittarium Pica – which is often linked to ciguatoxin. It is made up of carbon, oxygen and hydrogen in the chemical formula $C_{60}H_{86}O_{19}$. Ciguatoxin is produced mainly by dinoflagellates – a type of algae. The algae resides on coral and seaweed, which is eaten by herbivorous fish in tropical and subtropical areas. When these fish are eaten by humans, they can get poisoned by ciguatoxin. Ciguatoxin outbreaks are detrimental to the economy as they negatively impact seafood and fish markets. In the environment, fish infected with ciguatoxin can spread the illness to other fish when eaten. If more fish are infected, more are caught and eaten by humans. When ciguatoxin is digested by humans, it commonly affects the neurologic system, but also the digestive and muscular systems. Poisoned individuals may experience nausea, vomiting, and tingling toes or feet.

Batrachotoxin is a potent steroid-alkaloid found in poison dart frogs (Figure 3). The term 'batrachotoxin' was derived from the Greek word 'batrachos,' meaning frog. It is made up of oxygen,

Figure 3 – the poison dart frog

Figure 4 – a golden poison dart frog

nitrogen, carbon and hydrogen in the chemical formula $C_{31}H_{42}N_6O_2$.

Unlike the examples above, the frogs don't make the poison, at least not directly. In fact, the most realistic theory is that the amphibians draw the toxin from their dietary sources and secrete it through their skin. Therefore the toxins originate from the frog's food. When humans consume batrachotoxin through touching or eating a poison dart frog, it usually causes swelling, nausea and paralysis. However, some frog species are not poisonous at all, and some, like the golden poison dart frog (Figure 4) have enough poison to kill 10 adults.

So what about some venoms? Hemotoxin refers to hemotoxic venoms found in snakes such as vipers and pit vipers, as well as spiders such as brown recluse spiders. The term 'hemotoxin' comes from the Greek word for blood – 'hemo' or 'hema' – which means blood, because hemotoxins affect red blood cells (Figure 5) and the circulatory and cardiovascular systems.

It is made up from carbon, hydrogen and oxygen in the chemical formula $C_{17}H_{16}O_7$. Hemotoxin is created in the salivary glands of snakes – mostly vipers – and venom glands of spiders. Whenever humans get bitten by snakes or spiders, hemotoxins may be injected into the human.

The toxin severely damages the cardiovascular system, destroying red blood cells and causing swelling, internal bleeding, and in severe cases, necrosis or death.

Cytotoxin refers to cytotoxic venoms found in snakes – mainly cobras (Figure 7). The term 'cytotoxin' comes from the Greek term 'kytos' that means hollow, as in a cell. The word generally means a toxin that affects cells. Cytotoxin is made up of

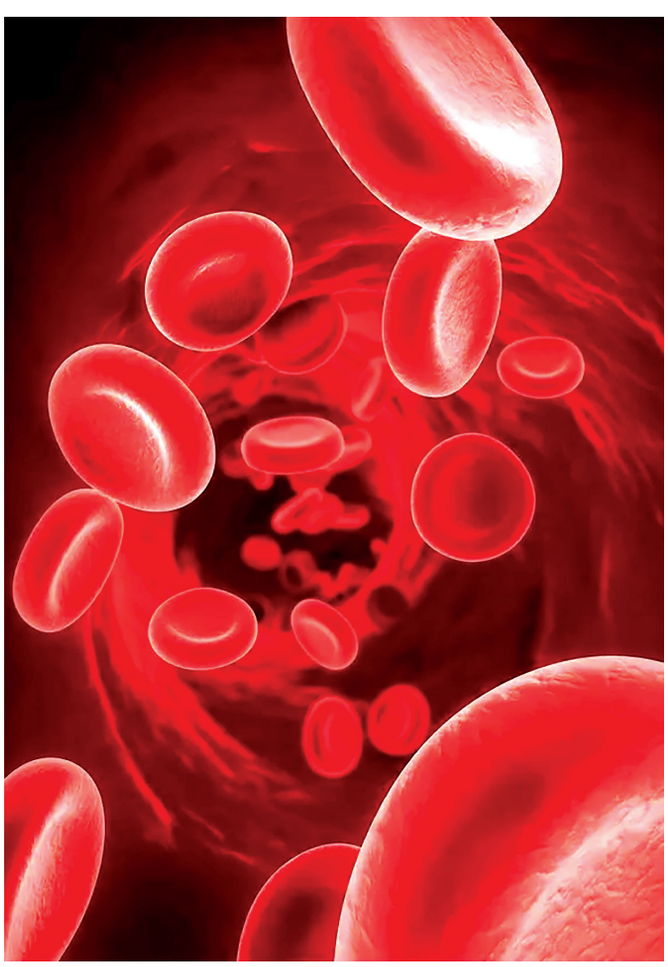

Figure 5 – Erythrocytes (red blood cells)

Figure 6 – The Russell's viper (*Daboua russelii*)

carbon, hydrogen, nitrogen, oxygen and sulphur in the formula $C_{299}H_{486}N_{80}O_{78}S_{11}$. The venom is produced by the salivary glands in the snake's head. Whenever humans get bitten and injected with cytotoxins, the venom severely damages cells or kills them. In extreme cases, this can cause necrosis and even death.

Gympietides are a newly discovered family of toxic peptides and neurotoxins. The term 'gympietide' comes from the Gympie-Gympie stinging tree (Figure 8) in which the venom was discovered. The plants make the venom inside themselves. When someone is unfortunate enough to come into contact with a Gympie-Gympie stinging tree (also called the suicide plant), the pressure makes needle like structures along the plant inject gympietides into the victim. The more you touch the plant, the more toxin you will receive, thus the worse the reaction will be. On contact with the Gympie stinger, immediate and intense pain will be felt.

Then, red or white bumps or spots will form. The venom then causes tingling in other parts of the body. It mainly affects lymph nodes, as they will swell in the affected area. Gympietides will not cause death – mainly just severe pain – and most symptoms will diminish in a couple of days.

Other venoms include Mastoparan in wasps, Verrucotoxin from stonefish and Tetrodotoxin, which is found in blue-ringed octopuses.

So in conclusion, when poison and venom were discovered, they changed the course of science, evolving intelligence for the future, not unlike what we are seeing AI do today. Understanding how these organic compounds work has led antivenoms being developed which help people survive encounters with these creatures. Scientists continue to embrace the evolution of intelligence, learning more about toxins and how they can help society understand more about the world around them. We may even develop AI that can identify poisons and venoms and treat their symptoms. Our community continues to grow in our knowledge of animals, and we hope to preserve these natural phenomena in the future.

Figure 7 – a King Cobra

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Figure 8 – a Gympie-Gympie stinging tree (*Dendrocnide moroidees*)

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Slugs have 4 tentacles on their faces that they use to smell and see.

From Data to Dominance: The Impact of AI on Formula 1 Aerodynamic Design

Words by Saverio Blefari (Year 9)

Thought starters

Formula 1 racing has long been a thrilling mix of speed, technology, and competition. Aerodynamic improvements have played a critical role in improving the performance of these high-speed machines over the years (see figure 1). The incorporation of artificial intelligence (AI) has ushered in a new era of aerodynamic design, promising not only quicker and more efficient Formula 1 cars, but also major societal benefits through the growth of AI technology. This article examines how AI-powered aerodynamics are altering the future of Formula 1 racing, increasing competitiveness, and contributing to broader AI developments that benefit society as a whole.

A Formula 1 car's aerodynamics are critical in influencing its speed, stability, and overall performance on the track. Wind tunnel testing and computational simulations have traditionally been used by engineers to optimise aerodynamic designs. These procedures, however, are time-consuming and constrained by human intuition. AI has transformed this process by allowing for the quick exploration of a huge design space, resulting in the construction of more sophisticated and efficient aerodynamic profiles.

Deep learning and neural network-based AI algorithms, in particular, excel at analysing huge volumes of data and detecting complex patterns that human designers may ignore. These algorithms can simulate and anticipate the intricate airflow patterns around a Formula 1 car, resulting in the development of novel aerodynamic layouts that maximise downforce while minimising drag. As a result, the car maintains stronger traction through turns and achieves higher top speeds on the straights, resulting in faster lap times and improved race performance.

The incorporation of AI-powered aerodynamics has significant ramifications for Formula 1 racing's competitiveness. Since teams have access to AI-driven design tools, the playing field becomes fairer, since both established and newer teams can use these technologies to improve the aerodynamic efficiency of their vehicles. This leads to more fierce racing on the track, where even minor improvements in aerodynamic performance can have a significant impact on race outcomes.

AI-driven aerodynamic improvements contribute to more thrilling and unexpected races. Drivers are encouraged to push their boundaries as cars become more able to manage different track conditions and traverse complicated

Figure 1- Mercedes AMG Project One, a production car based off of the Mercedes F1 spec car

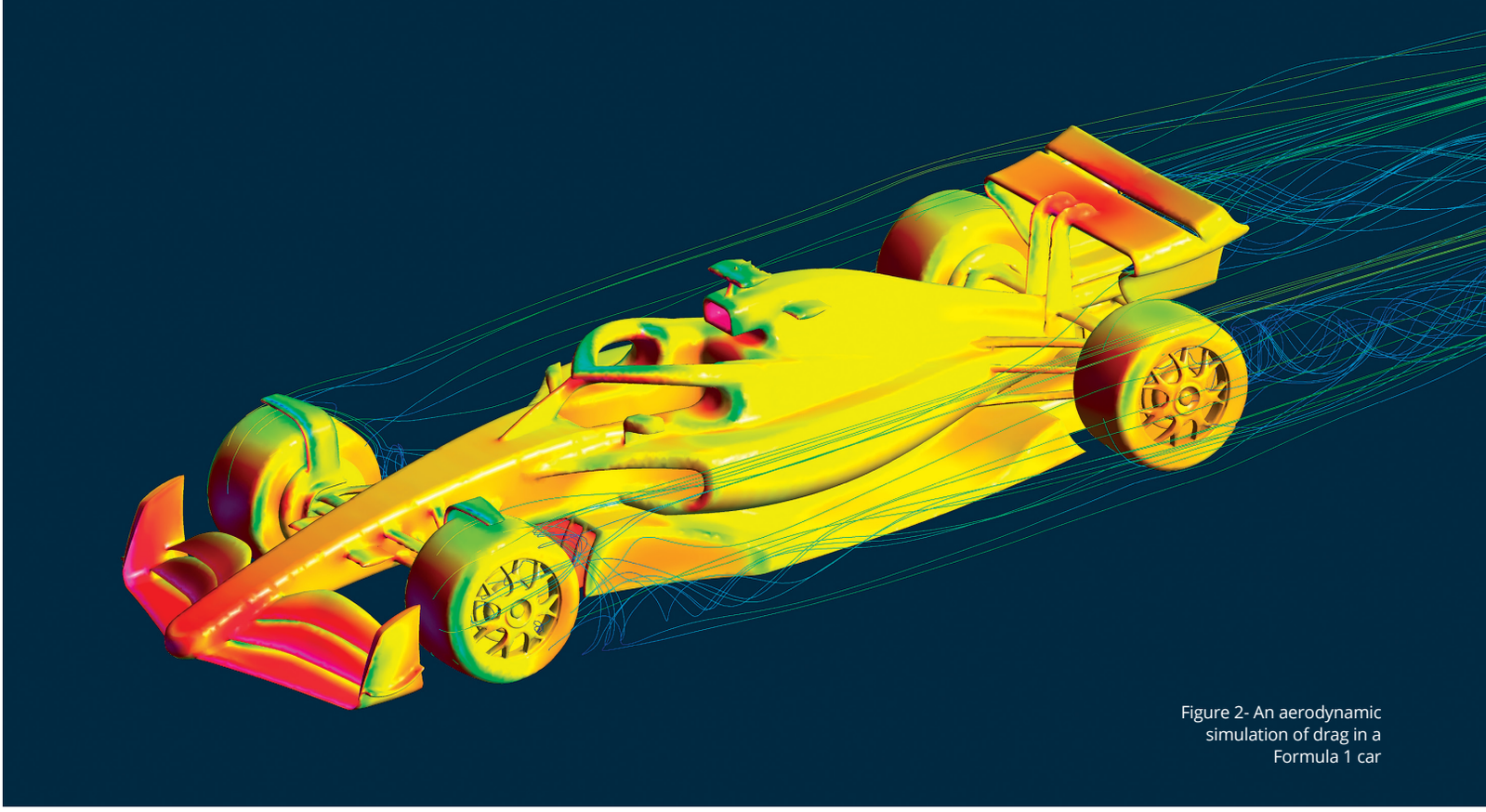

Figure 2- An aerodynamic simulation of drag in a Formula 1 car

corners, resulting in skilful overtakes and dramatic on-track confrontations. The greater emphasis on driver skill and strategy, rather than purely on car performance differentials, improves the entire spectacle of Formula 1 racing, enthralling viewers across the world.

Beyond the limits of the racetrack, advances in AI-powered aerodynamics have further societal consequences. The research and development necessary to produce AI algorithms that optimise aerodynamic designs enhances AI technology in general. The difficulties given by Formula 1's complicated aerodynamic regulations force AI developers to design novel algorithms capable of handling complex real-world circumstances, resulting in advances relevant to other disciplines.

For example, the computational approaches used to simulate airflow patterns around a Formula 1 car have applications in sectors such as environmental modelling, urban planning, and architectural design, in addition to tomorrow's road cars. AI-powered simulations could assist architects and engineers in optimising building designs for energy efficiency, predicting airflow in metropolitan areas, and mitigating environmental concerns. As AI algorithms improve their ability to handle complex fluid dynamics, their utility expands beyond the racetrack, positively impacting many facets of modern life.

The pursuit of more efficient aerodynamics is consistent with broader societal issues, particularly the fight for sustainability. The incorporation of artificial intelligence allows Formula 1 teams to optimise their cars for fuel efficiency, lowering their environmental impact. Teams can reduce drag by fine-tuning the aerodynamic profile, resulting in lower fuel consumption and emissions (See figure 2). This emphasis on long-term performance not only corresponds with global efforts to tackle climate change, but also highlights how advances in motorsport technology may impact the broader automotive industry.

The joint venture between Formula 1 racing and AI technology exemplifies the collaborative nature of progress. Formula 1 acts as a high-stakes testing ground for cutting-edge technologies, fostering innovation in fields such as materials science, energy efficiency, and data analytics.

AI-powered aerodynamics herald a watershed moment in the evolution of Formula 1 racing. Teams may create faster and more efficient cars by leveraging the capabilities of AI, boosting competitiveness and creating great racing spectacles. AI innovations have far-reaching impacts that extend far beyond the racetrack, influencing different socioeconomic spheres and driving breakthroughs that improve our daily lives. As Formula 1 pushes the limits of technology and performance, the symbiotic relationship between AI and motorsport promises a future in which innovation helps both the racing world and society as a whole.

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Taming the Beast of the Future? An Inquiry into the Future of AI.

Words by Sidhak Dhingra (Year 12)

Thought starters

ChatGPT's recent surge in popularity has brought the long-term implications of Artificial Intelligence (AI) into question. Paul Christiano is a researcher at ChatGPT's founding company, OpenAI. Midway through 2019, at an Effective Altruism global conference, Paul gave a presentation on '*Current Work in AI Alignment*'. Simply put, AI alignment is the ability of AI systems to align with human values or ethics. Although the talk is now dated over 3 years old, long term alignment issues raised at the presentation are as relevant, if not more relevant today. While I would recommend any person to watch the entire presentation, I would like to analyse one specific issue in depth. That is, can we give complete control to AI? If so, what are the implications? Firstly, we must define what is meant by 'complete control', Paul speaks of this in terms of the first 'handoff' from humans to AI. Basically, it is giving AI the autonomy to make decisions (otherwise made by humans). It is important to note, that this definition is still somewhat vague, however, drawing a definitive line for what complete control means is rather difficult. It seems unlikely that AI will take over human life in every aspect, nevertheless, its role in our day to day lives is becoming increasingly prominent. I believe, there are three central concerns to address if we are to give AI such power over our lives. The reliability of AI, our ability to verify AI decisions and finally, accessibility to such technology. Each of these central issues will be examined utilising ChatGPT in order to ground these concepts in everyday experience and to inform on the current stage of artificial intelligence.

It would be foolish to hand over any serious autonomy to AI if it cannot reliably complete the tasks we or itself sets out to do. Mr Christiano, breaks this down a step further, exploring the issue of competence. Most notably, AI is not doing what you want it to do; it is doing what it thinks you want it to do. So, ensuring that these two components align is critical, otherwise, even if it aligns with human values the AI will be prone to making mistakes. However, in the case of ChatGPT, it seems that it can consistently understand the stimulus provided (evidenced by the fact that it addresses the specific demands of each question), yet produces incorrect information. To understand why this occurs we must look at how artificial intelligence completes tasks. ChatGPT (like other AI systems) uses a process called machine learning in which it imitates human intelligence through training on extensive datasets. More specifically, it 'strings' together words through algorithms it has generated from the datasets it learnt from. In this way it predicts the next word from the current word,

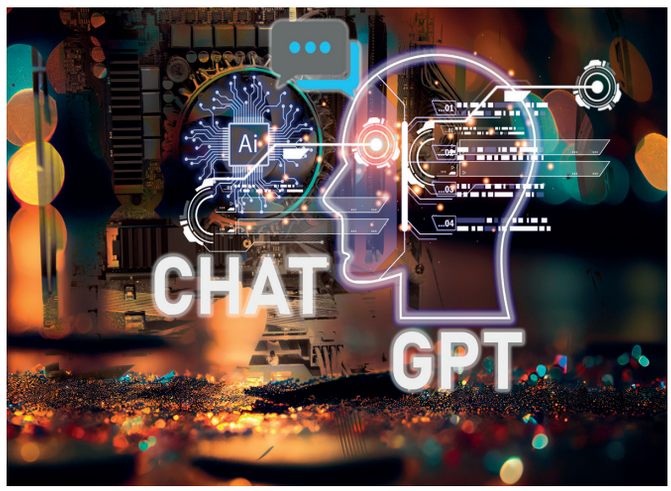

Figure 1

which explains why it seems so formulaic in its responses to prompts. Currently, there is an awareness that ChatGPT is not perfectly accurate even though it is competent. This would likely need to be addressed before AI starts taking on decisions with higher stakes. With that said, there are other uses of ChatGPT which do not succumb to this issue. In cases without a clear distinction between right and wrong ChatGPT excels, given that it cannot be correct or incorrect anything produced by the AI is inherently reliable. Part of the reason ChatGPT is so revolutionary is due to its creative capabilities, but it is important to mention that it has been tamed. ChatGPT seemingly has its own moral code, accordingly, it will refuse requests that it deems may be offensive or inappropriate. These are manually put in place to enable it to align with human values, yet it also signifies our inability to surrender full control. Had we not put such measures in place, the implications would be rather problematic. Microsoft's abysmal failure with its AI Tay is a prime example of this, where it began spurting inflammatory remarks in a public forum. In this way, any intelligence we give the power to inform must also be reliable in that it promotes positive messages. Paradoxically, it cannot decipher itself objectively what we humanly prescribe as positive or negative. It must develop an algorithm to align to our understanding of the terms. The issue of reliability is multifaceted in that it must first be able to interpret the prompt (reliably) then respond (reliably) in a way that does not endorse poor values.

Let's imagine that we have an AI system that is reliable. We then need to verify not just the reliability itself but also the conclusions formed. Within his presentation, Paul Christiano refers to this verification of outputs as 'outer alignment' and examines the issue from 2 perspectives. Firstly, the 'learn from teacher' approach where he implies there is some human with greater knowledge of the area than AI and thus can deliver a judgement on its output with human values inherent to the judgement. The machine can then utilise this in one of three ways, it can either 'imitate the teacher', treat the feedback like a dataset and learn from it or, (ambitiously) attempt to infer the preferences of the teacher. However, all this analysis revolves

around the premise that there is the ability to consult other sources with superior information that the machine can learn from. But the nature of machine learning would mean there would come a point where the machine would overtake (or at the very least, equalise) the source it is learning from. If we accept that the machine now possesses a greater knowledge of the topic, we lose the ability to verify the information produced. This comes with the risk of spreading false information (which one could argue is not even false given that it cannot be proven false) to the user of the technology. And the convenience of services such as ChatGPT only amplifies this issue as we may not challenge the knowledge produced even with access to other resources. Not to be defeated, Paul Christiano proposes that when AI surpasses human capability we strive to understand the system. That is, the methodology used internally to produce the answer, that it be transparent to us, not 'opaque'. This suggests, in the event that learned machines produce incorrect information an understanding of the systems nature will enable us to evaluate the claim. Tying this back to the focus question, we may well give control to AI as long as its decision-making process is accessible and can therefore be verified by us. Without any understanding of how a decision was reached, it seems very difficult to trust the conclusion. Ultimately, it is our trust which AI must attain.

Finally, if we are to complete this 'handoff' to AI we must question who is able to yield such technology. It is remarkably difficult to come to a sound and just conclusion, even so, these issues must be examined from different perspectives to understand the complexities. OpenAI opted to make ChatGPT accessible to the general public. Although loosely it gave equal access, students from middle school to university were quick to exploit the technology to complete assigned tasks. There were primarily two polarised responses to this behaviour, firstly, that it is cheating. Alternatively, that education has been advanced and teaching must evolve. It is challenging to predict this issue in the context of more powerful AI. It may even be that AI is teaching children in the future. Nonetheless, it does show that even now, the advancements in AI can be exploited and that this issue will remain prevalent as AI progresses. Moreover, with the release of GPT-4, OpenAI placed a monthly subscription fee to access the machine. As such, only those with the financial means can access this technology, which arguably provides them with an advantage over those who cannot afford it. If AI is to surpass human capabilities such paywalls would be unethical to impose. Imagine there are two websites in the designing process, the first one is produced by a human with his own subjective biases influencing his design choices. The second, produced by an AI algorithm which has studied billions of user interactions with websites and has near perfect understanding on how to maximise traffic retention. Juxtaposing the two websites shows the competitive advantage entities could gain if they had sole access to such technology. However, even if the technology is distributed without any restriction and suddenly both websites are perfectly curated this gives rise to other ethical concerns. We would be sacrificing some degree of our own autonomy, as these sorts of interactions where one entity is attempting to persuade the other (in this case for a transaction) will be optimised to exploit human fallibility. Say we set standardised regulations for the use of AI, in these situations firms would be incentivised to disregard these if it meant any advantage in efficiency or innovation. Perhaps there will be AI to regulate AI, but then, who regulates that AI? All in all, access to any powerful or autonomous AI seems to give rise to a range of ethical concerns. Unfortunately, regulating the exploitation of such technology seems even more problematic.

Whilst the rapid advancements in artificial intelligence have immense potential, the ethical implications are of arguably greater concern. It seems unlikely that we will give complete control to AI due to the risk it incurs. However, it seems that the role AI plays in our lives is set to steadily increase with improvements in both the technology and its alignment to human values. Unfortunately, this inquiry has raised more questions than answers, however, these questions are absolutely critical to explore. The power of AI is far too large to be mishandled.

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ChatGPT costs over $1,000,000AUD to run every day. On average, that breaks down to 56 cents per question

Could Mynvax's thermotolerant coronavirus vaccine help to better serve poorer nations and remote communities?

Words by Jesse Rothgrew (Year 11)

Biology

In 2020, Covid-19 was the 3rd leading cause of death in the United States of America, with over 350,000 cases where Covid-19 was identified as the underlying cause of death. Biotech startup Mynvax has developed a heat-tolerant 'warm' Covid-19 vaccine, which can remain stable at 37C for up to 4 weeks. Mynvax collaborated with many others and were very transparent with their findings to the public.

Covid-19, is an infectious disease caused by the SARS-CoV-2 virus. The virus enters the body and binds to the angiotensin-converting enzyme 2 (ACE2) receptor via its complementary spike protein (Figure 1), entering the cell and hijacking cell replication. This can cause damage to the endothelium tissues, specifically of the lungs, liver, kidneys, and brain, which can lead to flu-like symptoms, fatigue, and death (0.8% fatality rate). Covid-19 vaccines (such as Mynvax's) work by inserting a mRNA strand into the person, which codes for the same spike protein used by the virus, causing our body to synthesise the protein. Our body then manufactures antibodies with the complementary variable domain to the spike protein, meaning that if we are infected with Covid-19, our body is already able to eliminate it, reducing our symptoms. When the virus mutates, the spike protein's shape changes, meaning the vaccine's spike protein no longer matches that of the new strain of the virus, and is no longer effective. Therefore, updated vaccines need to be created and administered frequently to match the shape of each new strain of the virus to remain effective.

Mynvax's vaccine uses the same premise as the previous mRNA vaccines, however they designed and engineered a trimeric, glycan receptor binding domain (RBD) which increased the vaccines thermotolerance. They then lyophilised (freeze-dried) the RBD, which further increased its ability to remain functional at high temperatures. These allowed their vaccine to remain functionally stable for 90 minutes at temperatures of up to 100C, and 4 weeks at 37C. This is exceptional when compared with Pfizer's vaccine, which lasts only 24 hours at 8-30C, 10 weeks at 2-8C, and 18 months at to C. Mynvax's initial tests have been promising, as their vaccine consistently and effectively created the antibodies required to neutralise the Alpha, Gamma, Beta, and Delta strains of Covid-19 within their hosts, showing that their vaccine can be adapted to new strains of the virus.

The pandemic caused disastrous repercussions for the world which was the major influence in creating a safe and quick vaccine. As stated previously, Covid-19 can adversely affect an individual's ability to function, which normally lasts around a week. The severity of the virus influenced governments to lockdown in an effort to slow the spread of the virus. In 2021 alone, the Australian government had to pay over $290 billion to small business owners and employees who were unable to work due to these lockdowns. Furthermore, a majority of young Australians said that Covid-19 had a negative impact on their social interactions with family and friends, education, and sleep. As such, the development of this vaccine was influenced by the social and economic impacts of the virus, and the need this created for a vaccine.

This was not the first Covid-19 vaccine to be developed though, and it was clearly influenced by some of the challenges created by the previous 'cold' vaccines. Whilst Mynvax is yet to release their long storage data, given its thermotolerance, it's likely to remain functional at considerably higher temperatures than Pfizer's vaccine, making it favourable for distribution to areas without the otherwise necessary specialised and expensive refrigeration equipment. The current transportation, storage, and distribution method for Covid-19 vaccinations involves multiple steps, with the temperature needing to remain within the aforementioned to C range, posing serious financial and logistical concerns. In 2021 alone, over 8% of the cost of the vaccines was due to the equipment needed to store the 'cold' vaccines. In contrast, Mynvax's vaccine would not require this specialised equipment, reducing the costs involved with transportation and storage, decreasing the price to governments and increasing the amount of Covid-19 vaccine they can purchase and administer.

Additionally, the need for a cheaper and 'warm' vaccine in less developed countries was a key factor in the development of this vaccine. As stated previously, cold storage equipment is expensive, which makes it harder for poorer nations to vaccinate their population. For example, just over one quarter of the required vaccines have been administered across all of Africa, but this isn't because the vaccine itself is too expensive or rare. Australia discarded 20% of its national supply because there were no countries prepared to receive them, suggesting that the issue with distribution resides in their need for cold storage, rather than the quantity of the vaccine itself. Given that poorer nations and remote communities have less cold

storage capabilities, Mynvax's 'warm' vaccine could make the distribution of a Covid-19 vaccine easier and cheaper, potentially improving the global vaccination rate.

Throughout the project, Mynvax worked with various government agencies and foundations to facilitate the development, creation and testing of their vaccine. The development of their vaccine was sponsored by a grant from the Bill and Melinda Gates foundation and from the office of the Prime Ministers Scientific Adviser in India. These grants facilitated the development and creation of the different formulations, as well as providing the option to consult on future potential issues. The testing stage was funded by a major grant from Australia's Department of Finance to the CSIRO, the agency which would analyse the results of the tests. Without the support of various agencies, this vaccine would never have been developed, showing the importance of such a vaccine to society.

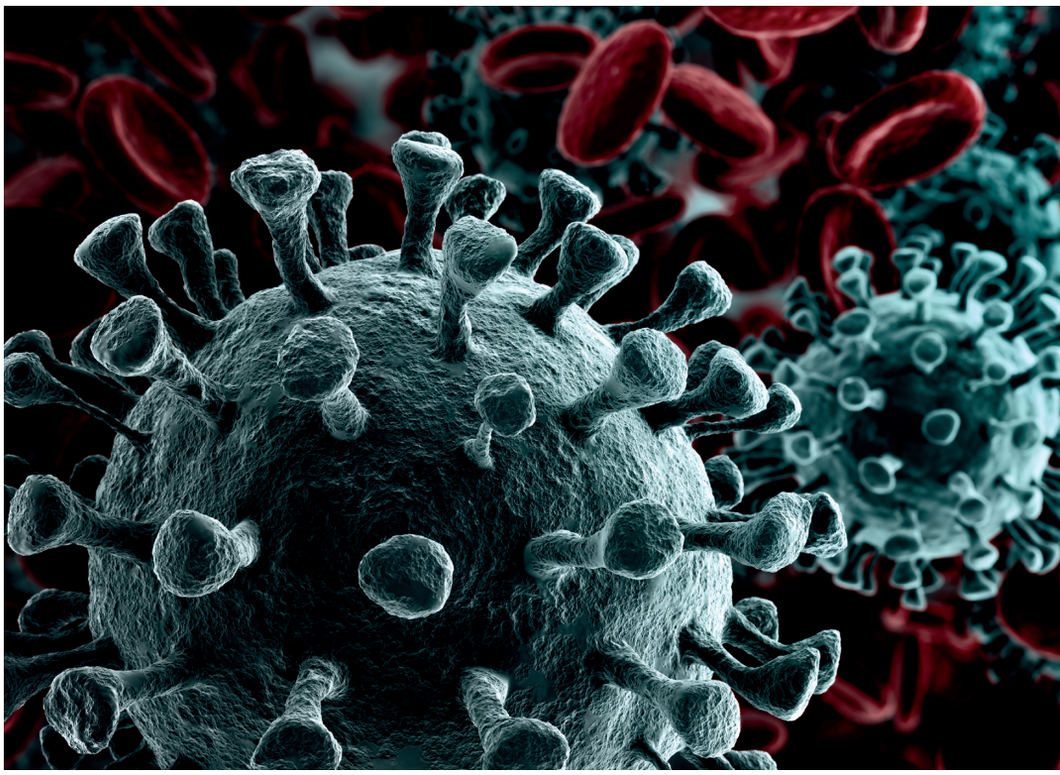

Figure 1: SARS-CoV-2 virus with surface spike proteins

In developing the vaccine, Mynvax collaborated with various doctors and researchers to create their formulations. This was aided by the World Health Organisation, who encouraged intellectual property (IP) waivers for Covid-19, which expedited the collaborative process and allowed scientific ideas to be more easily shared. For example, Dr Neil King provided the ACE2's fusion protein, Dr Barney Graham provided the Spike protein's construct, and the Centres for Disease Control and Prevention provided the initial coronavirus reagent and isolate. The sharing of this knowledge was essential, reducing the time required to spend on development, as they could build on the work of their fellow researchers. The implementation of the IP waivers showed how urgent the need for the vaccine was, and as Mynvax utilised them throughout the creation of their vaccine, this showed how the needs of society can influence the scientific process.

Once they had created a number of possible formulations, they were tested using mice, hamsters, and guinea pigs. The variants used to infect the hosts were provided by the Victorian Infectious Diseases Reference Laboratory, and included the Alpha, Beta, Gamma and Delta strains of the virus. CSIRO's scientists at the Australian Centre for Disease Preparedness in Geelong then evaluated the efficacy of the vaccines by comparing their blood samples with positive control ferret sera (provided by the University of Oxford) and concluded that all the formulations tested resulted in antibodies that were capable of consistent and effective neutralization of all the major variants. In 2021, they communicated their findings by publishing a scientific paper in the National Institute of Health's journal, which was written by and for scientists. The CSIRO also wrote about the vaccine and its potential applications; however their article is designed to be accessed, read, and understood by the general public, therefore this is how society as a whole learnt about the vaccine.

Mynvax's thermostable vaccine is now waiting for the planned phase 3 clinical trials to begin. If this vaccine were to be approved, then it could help to lower the costs involved in the transportation and storage of Covid-19 vaccines. Not only would this better serve the rural and remote communities within Australia where it is harder to store the alternative 'cold' vaccines, but it could also improve access to Covid-19 vaccines around the world, especially in poorer nations. It is clear that Covid-19 can lead to severe medical complications, and its damage to the social and economic health of a country may be equally severe. So far Covid-19 mutations have been less severe, however if a mutation was to become more deadly, then this vaccine could be the quickest, cheapest and easiest way to vaccinate people in rural and remote communities, as well as poorer nations throughout the world.

In conclusion, by being able to produce a thermostable Covid-19 vaccine, they've potentially reduced the cost of distributing the Covid-19 vaccine, thereby improving access to the vaccine for billions around the world. Specifically, this would be most beneficial to remote communities and poorer nations whose hospitals don't have the equipment or budget to store the alternative 'cold' vaccines. If ongoing vaccination is required to stay protected against Covid-19, then Mynvax's vaccine could improve the healthcare of billions around the world, saving lives and money in the process.

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Octopuses Have Three Hearts: Two that pump blood to the gills, and a third that pumps oxygenated blood to the rest of the body.

How have recent advances in knowledge of the CFTR protein assisted scientists with improving cystic fibrosis treatment?

Words by Kristian Commons (Year 12)

Biology

Across the globe, there is an approximated number of just over 100,000 people who suffer from cystic fibrosis (CF). The disease affects sufferers in various ways, as seen in Figure 1. However, families and partners of CF sufferers are also impacted as the shortened life span of their loved one brings much grief. Hence, there are various institutions globally which are constantly seeking to improve the treatment available for those in need. Recently, knowledge has been gained with regard to the impact of mutated DNA within lung cells, and how this can impact the functionality of protein channels in these diseased cells. This article will explore the collective effort of various people with different expertise to analyse components of cystic fibrosis, as well as the advancing knowledge in membrane protein function which has led to the continual development of cystic fibrosis treatment.

The CFTR gene provides instructions for making a protein called the cystic fibrosis transmembrane conductance regulator or CFTR, which functions as a regulated chloride channel in the membrane of cells including those of lung tissue cells and sinuses. Research has found that two nucleotide-binding domains (NBDs) within CFTR dimerise (join together) prior to the opening of the protein's channel. Mutations to the CFTR gene causes defects in the functionality and/or production of CFTR proteins, leading to the presence of cystic fibrosis in an organism. There are various possible mutations to the CFTR gene including the gating and conductance defects among others. The gating defect impairs the regulation of CFTR channel, commonly leading to permanent closure of the passageway. Conductance defects impede the ion conduction pore by changing the shape of the channel's interior. It has been recently found that potentiator drugs (correctors) can enhance channel activity by increasing pore opening of CFTR proteins. Ivacaftor, a particular potentiator drug, assists with reducing the intensity of gating and conductance mutations. It does this by allowing a greater proportion of chloride ions to move in and out of cells, balancing salt and water levels in the lungs and reducing symptoms of CF . A visual representation of the action of Ivacaftor and the dimerization of the NBD is seen in Figure 2 below.

A combination of biological examination methods were employed to discern the relationship between the CFTR channel's structure and function. These methods included that of Cryo-Electron Microscopy (Cryo EM), electrophysiology, and smFRET. Cryo-electron microscopy is a structural biological method that is used to determine the 3D structures of biomacromolecules. The utilisation of Cryo-EM allows for high-resolution structures of biomolecules to be found whilst eliminating flaws that are found in other methods, such as molecules not crystallising in X-ray diffraction. This benefit is key for analysis of CFTR, as this protein cannot crystallise.

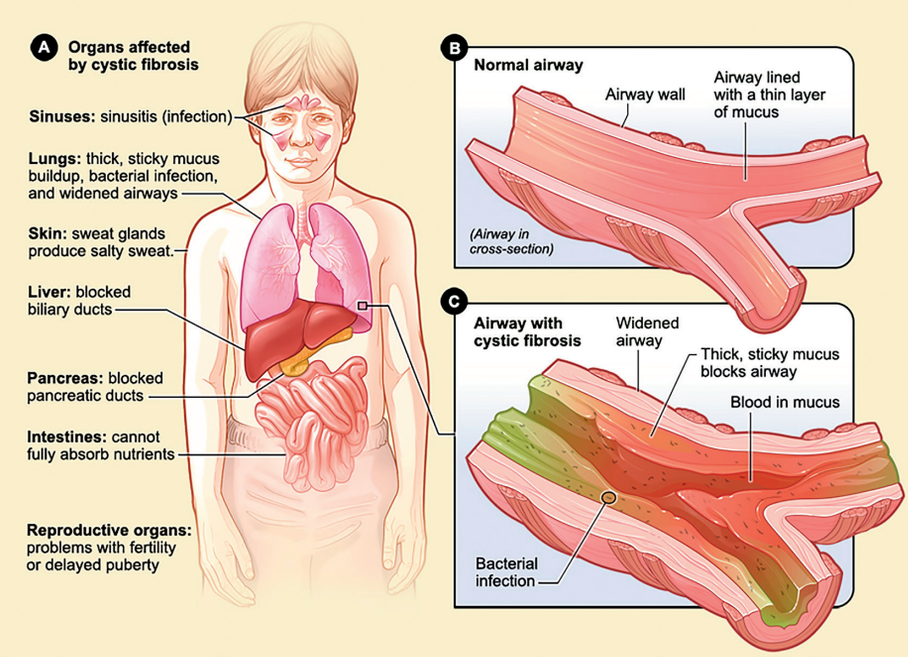

Figure 1: Image denoting common symptoms of CF

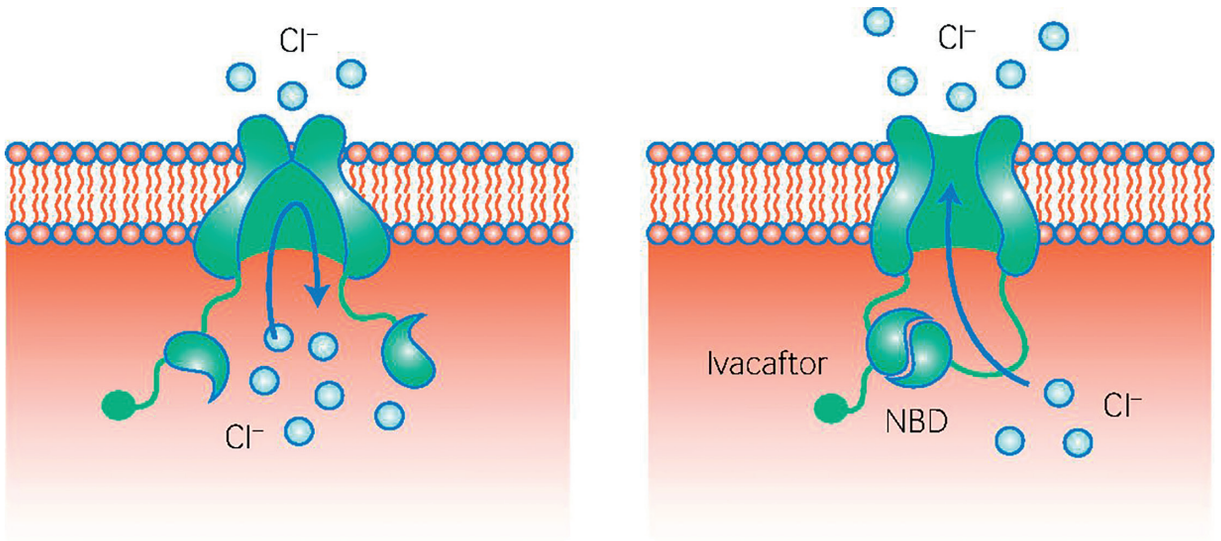

Figure 2: Mechanism of action of Ivacaftor on mutated protein channel.

Cl^- = chloride ion. NBD = nucleotide binding domain

Another method used to gain insight into the moving parts of the CFTR protein was smFRET. smFRET is a method which can reveal the functions, kinetics, and conformation dynamics of individual biomolecular machinery, such as the CFTR protein. smFRET is an application of FRET, with FRET being a distance-dependent process used to track proteins or measure distances between their domains by tagging different regions using fluorophores and measuring the distance of emission.

Various groups contributed to research and review findings with regards to understandings of CFTR channel structure and function. The collaboration of these groups was vital in the success of their research, as the unique knowledge of each individual allowed for creative discussion and ideas to be cultivated. Scientists from both St. Jude's Children's Research Hospital and Rockefeller University collaborated to gain knowledge in the field of CFTR structure and function. The smFRET method was developed by the St. Jude team, playing a key role in the research. The scientists from Rockefeller were able to manipulate this method and draw connections between the dimerization of the nucleotide binding domains and the impacted effectiveness of the CFTR's function. Through this correlation between the conformational changes and the CFTR's function, the underlying structural biology could be assessed by the scientists, the resulting knowledge applicable in improving treatment for CF.

Furthermore, the cooperation is evident between cystic fibrosis research firms and funding benefactors, such as the government and other external supporting companies. JAMA network outlines that from 2008 through to 2018, federal funding for CF across the US was in excess of $2500 for every individual sufferer. The collaboration between the US government and research facilities emphasises how their unification is imperative for the cultivation of sufficient funds to assist with the success of this scientific enterprise.

Moreover, the communication between scientists and community is evident as awareness of cystic fibrosis' effect on sufferers is raised through publications on many websites such as The Cystic Fibrosis Foundation and also Cystic Fibrosis Australia. Both organisations have basic scientific information targeted to the general public, and there are fundraising options available via the website to encourage the support of this scientific field from society. Additionally, during May each year, the Cystic Fibrosis Foundation have a month dedicated to raising awareness of CF, so people can share experiences via various social media platforms.

The influence of societal pressure to make advancements in this field is necessary to better the lives of many CF sufferers across the globe. Cystic fibrosis negatively impacts the lives of many people, whether they are a sufferer or a familial member of such, introducing the requirement of costly treatments and mental stress. This influenced the need to find ways to improve quality of life for these individuals.

The research conducted by the scientists was influenced by previous advances in scientific knowledge surrounding differing CFTR conformations, as well as the development of analysis techniques created by the team from Rockefeller University. The team from Rockefeller had previously discovered the presence of two distinct conformational structures of the CFTR at different times, and this allowed for further investigation to discover the role of dimerization in the channel's function.

Additionally, the presence of economic considerations are a factor impacting this research. The funds necessary for extensive research into CF are significant, with the Australian Cystic Fibrosis Research Trust funding more than $6,000,000 of CF research over the past decade. This funding goes towards constructing scientific equipment, sourcing required substances and the employment of staff within various institutions. Society is influenced by this as the cystic fibrosis field provides occupation for many citizens, as well as volunteering opportunities for young and old people. The cystic fibrosis foundation alone has 500-1000 employees and 250,000 volunteers, and an extensive number of scientists and researchers are employed across the globe contributing to this field.

The research undertaken was influenced strongly by the necessity to improve techniques previously discovered such as X-ray diffraction and nuclear magnetic resonance (NMR), which are both used to study the physical and biological properties of matter. However, their inefficiency in profiling certain proteins,

including that of CFTR, lead to the development and application of new methods to overcome this fault. The use of these improved techniques allowed for advancements to be made in the cystic fibrosis field.

The advancing understanding of CFTR channels and various aspects of analysing the mutated DNA will most notably contribute towards improved diagnosis and treatment in future years. The usage of Cryo-EM will likely be applied to assess various proteins in the future, as the method has been found to be effective during the assessment of CFTR channels. There is possibility for researchers in the future to further develop understanding of CFTR function and its role in cystic fibrosis sufferers using the knowledge and methods from current scientists. In addition, the requirement of further funding toward research and development of CF treatment in the future will incur significant costs to various government organisations, impacting the economic circumstance of these institutions. This factor has the possibility to create limitations for research moving forward, especially with the favouring of research into other chronic diseases, for example cancer, receiving over $930 million from 2018-2020

Overall, the improved understanding of CFTR structure and function has arisen through the collaboration of several groups' combined knowledge and the application of old and new techniques. From this, progressively enhanced treatment can be developed, brightening the future of cystic fibrosis patients worldwide. Although a cure for CF has not been found, constant research into the mechanics behind the disease allows for the improvement of treatment, therefore enabling sufferers to have increased longevity and access to a better quality of life.

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What is the future of diabetes treatment?

Words by Marcus Gibson (Year 12)

Biology

Type 1 diabetes is a chronic autoimmune disease in which the insulin producing beta cells in pancreas are attacked by the immune system. The cause of type 1 diabetes is unclear. Type 2 diabetes, on the other hand, is where the body does not produce enough insulin or becomes resistant to the insulin it secretes. Type 2 diabetes is caused largely by environmental and lifestyle factors such as unhealthy diets and physical inactivity. Without insulin, glucose builds up in the bloodstream, causing a range of consequences such as blindness, kidney failure, heart attacks, strokes, and lower limb amputations. However, when diabetics can keep their blood sugar within a 'normal' range of 3.9 -5.6 mmol per litre of blood, these consequences are much less likely, and they are able to live 'normal' lives.

Past treatments for diabetes used insulin extracted from pigs, but they have evolved to synthesised human insulin and some devices that monitor and control blood glucose levels. For example, Continuous Glucose Monitors (CGMs), sitting in the interstitial fluid between cells, and insulin pumps, which try to replicate pancreas function, releasing insulin into the blood when glucose levels rise. However, the reliability and accuracy of these devices is not enough to effectively treat the condition. This has influenced the biotechnology industry to develop more efficient techniques of managing blood sugar. One such development, researched by a Swiss university named ETH Zurich, is an implantable metabolic fuel cell (Figure 1), paired with artificial beta cells (Figure 2). This combination treatment may be the future at keeping this range of blood glucose concentration more stable.

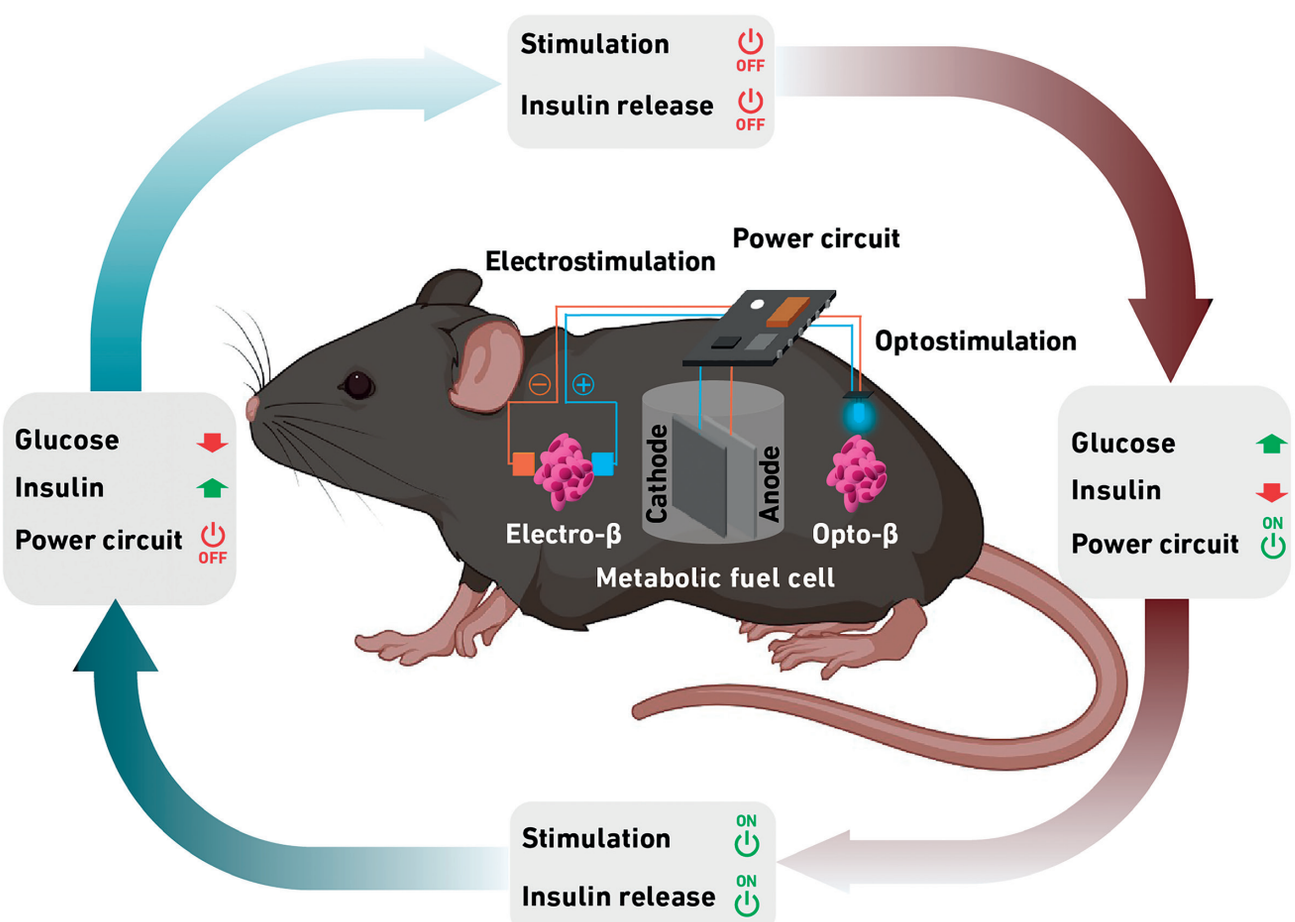

Figure 1: The fuel cell in mice

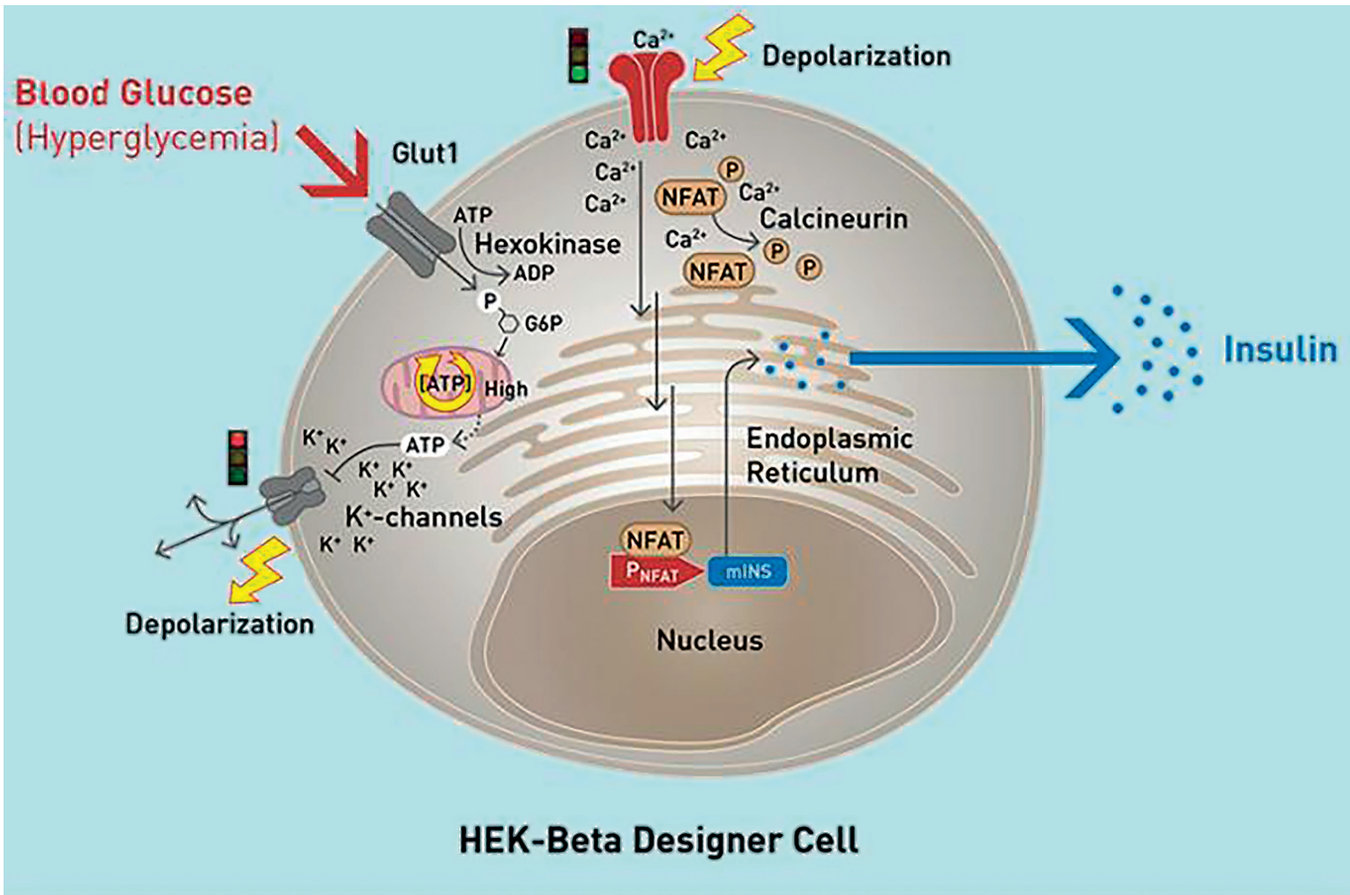

Figure 2: An artificial beta cell

The fuel cell, seen above in a mouse has two major components and is paired with a further biotechnological development in the form of artificial beta cells for better blood sugar control. The small package that is the fuel cell is wrapped in non-woven fabric, coated in alginate, and contains an anode of copper-based nanoparticles. The alginate allows for the blood to be absorbed through the non-woven fabric due to its exceptional ability to absorb liquids. The blood then travels through the copper anode, where the copper nanoparticles react with the glucose in the blood stream to produce gluconic acid and a proton. This proton is where the electric charge is produced. This electrical charge is paired with ETH Zurich's other development, artificial beta cells (Figure 2).

Unlike previous attempts to recreate beta cells using stem cell research, Martin Fussenegger of ETH Zurich used kidney cells, known as HEK cells. Naturally occurring glucose transport proteins and potassium channels were used in the HEK cells and were enhanced with voltage-dependent calcium channel and a gene that produces insulin as well as GLP-1, a hormone involved in the regulation of the blood sugar level. These beta cells are activated by the charge produced by the fuel cell, and function exactly like beta cells from the pancreas.

Diabetes is a chronic condition in which the patient's body cannot produce insulin or does not respond to the insulin it produces. In the United States, 37.3 million people have diabetes (type 1 and 2). Of these cases, 8.5 million are undiagnosed and have no access to even the unreliable and inaccurate treatments available to diagnosed diabetics. As well as the aforementioned significant impacts on physical health, the lifestyles that diabetics need to live is severely detrimental to their mental health. The Centre of Disease Control and Prevention defines depression as an illness that causes feelings of sadness and a loss of interest in activities you used to enjoy. People with diabetes are 2 to 3 times more likely to suffer depression. Among this group, only 25-50% get diagnosed and treated with remedies that are usually very effective. In Australia in 2018, diabetes and its underlying consequences accounted for around 16,700 deaths, while the number of people with diabetes in the world has risen from 108 million in 1980 to 422 million in 2018 and seems to be continuing to rise. This creates large ethical and social problems, creating a strong need for a new technology to limit the elevated blood sugar in diabetics.

Further, the current treatments for diabetes have large economic influences. In the United States, 1 in every 4 dollars spent in health care is on diabetes. This figure is similar in most 'western' countries. These prices include insulin, pumps, and continuous glucose monitors. The total annual cost of diabetes in the US was $327 billion in 2017. Around 50% of lifetime medical costs for diabetics are for complications with diabetes, such as heart diseases and strokes. Diabetics are under immense pressure to be able to afford the treatments that allow them to live, influencing the need to create a cheaper, more efficient system. When fully constructed, the fuel cell and beta cell complex will only require one insertion, and is constructed of relatively small, cheap components.

Microbial fuel cells are a promising renewable bioenergy source, using biofilms as biocatalysts to create a charge from

organic matter. Copper based materials being used for anodes and cathodes have been researched for lithium-ion batteries, because of their high electrical and thermal conductivity, due to their unique nanostructures. These attributes make them perfect for implantable fuel cells, as the nanoparticle form of copper is microorganism free and is non-corrosive.

This new development also provides a much sounder framework for treatment of high and low blood sugars. The artificial beta cell and fuel cell partnership helps solve the numerous problems associated with both insulin pumps and CGMs. Insulin pumps are designed to replicate pancreatic function by injecting insulin when needed, however have multiple issues with their function. They often do not deliver the full dose of insulin due to bubbles or blockages in the system. Also, leakages frequently occur due to problems in the pumps' rubber seals. The pump can often become loose around the injection site and fall out of the skin. Bleeding, scarring, and infections are not unusual when using a pump to treat diabetes. These problems would be avoided using the artificial beta cells, as no injection is needed after their initial insertion. Furthermore, the artificial beta and fuel cell treatment also reduces the risks associated with CGMs. The main problem with CGMs is how they measure blood glucose levels. They measure interstitial glucose levels, which is the glucose found between the cells. Although they measure every few minutes, the interstitial glucose level is always slightly different to that of the blood glucose level. This creates inaccurate readings, as well as lagging approximately 20 minutes behind the blood sugar level at the time of the reading. This creates further disparity as the user of the monitor can make wrong decisions on the dose of insulin to inject as they don't have the correct blood sugar level reading. The use of ETH Zurich's new development does not use any monitor apart from the actual blood glucose level at the time.

As this technology and its consequences are very new and largely untested, it could take years of further refinement and development to produce a viable fuel and beta cell pairing, effectively a cure for diabetes, and release it to the market. The research conducted at ETH Zurich concluded that the fuel cell showed promising results in mice but will need to undergo several clinical testing stages in humans before it can be used on a wider scale. However, once this wider scale is reached, the possible application for this technology represents something as close to a cure for diabetes than has been seen previously. Ultimately, the implantable fuel cell, paired with the artificial beta cell, investigated at ETH Zurich are a pathway to a future without the economic and social problems that diabetes causes.

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Bananas contain radioactive potassium.

The Human Genome Project: Implications For Medical Science

Words by Sage Goel (Year 7)

Biology

The Human Genome Project (HGP) was perhaps the greatest scientific feat in history. Unique in its approach; it was a highly collaborative, international effort. Its mission: to sequence nature's unique, carbon-based system of intelligence.

Launched in 1993 and completed in 2003, the Human Genome Project (HGP) provided fundamental information about the human blueprint. Now, with the evolution of contemporary biotechnology, the application of the HGP have expanded dramatically. Unprecedented advances in the knowledge of health and disease have come to light because of this evolution, in turn, revolutionising the practice of mainstream medicine.

However, first, let us take a moment to understand the history behind this breakthrough. After all, it is through understanding the past that we gain an appreciation for the contemporary.

Seventy years ago, James Watson and Francis Crick (shown in Figure 1) took genetics into the molecular world. Recognising early on in their careers, that an appreciation of the three-dimensional composition of deoxyribonucleic acid (DNA) was essential if heredity was to be understood. Drawing on experimental results provided by Rosalind Franklin, the duo established that DNA was constructed from two linked strands, which wound around each other to create a helical structure, as shown in Figure 2.

Each strand, they determined, had a 'backbone' made up of alternating deoxyribose (sugar) and phosphate groups. Attached to each sugar was one of four nucleotide bases, which paired precisely through hydrogen bonding with their 'complimentary partner.' Specifically, adenine (A) paired with thymine (T) and cytosine (C) bonded with guanine (G).

It was this discovery, that established the foundation for the ground-breaking research into the genetic code and protein synthesis, that followed. Prior to the 1950s this had been poorly understood at a molecular level.

After the discovery of the double helix, DNA research began to gather momentum. Initially driven by Crick himself, who postulated that genes, the basic units of heredity, were constructed from DNA. Following this, the process of DNA replication and eventually how proteins were synthesised, was elucidated. With these discoveries, excitement mounted within the scientific community. As the realisation dawned, that

Figure 1: James Watson and Francis Crick and their DNA model (Cavendish Laboratories, 1953)

through sequencing DNA, the 'map' of humankind may one day be determined. Numerous attempts were subsequently made to sequence DNA in the early 1970s. However, it wasn't until 1977 that a sustainable sequencing method was developed by Francis Sanger. His technique, known as 'Sanger Sequencing,' involved combining single strands of DNA with the 4 free nucleotides from which DNA was composed. Then, by observing which nucleotides attached to the DNA, small segments of DNA were able to be sequenced with 99.9% accuracy.

This technique was used almost exclusively over the following 40 years and is still used today to sequence small fragments of DNA. In fact, it was an adaptation of the Sanger sequencing method, which was ultimately used to sequence the human genome.

The idea that the human genome should be sequenced was first put forward in 1984 by Renato Dulbecco. He postulated that mapping the human genome would facilitate a greater understanding of cancer. This in turn, would allow for more efficacious treatment options to be adopted. His proposal followed the successful sequencing of a variety of bacterial and yeast genomes and yeast. This led scientists to believe that the time was right to attempt the mammoth task of sequencing the human genome.

In 1985, a meeting focussed entirely on the merits of the HGP was held amidst significant controversy. It's agenda; to debate

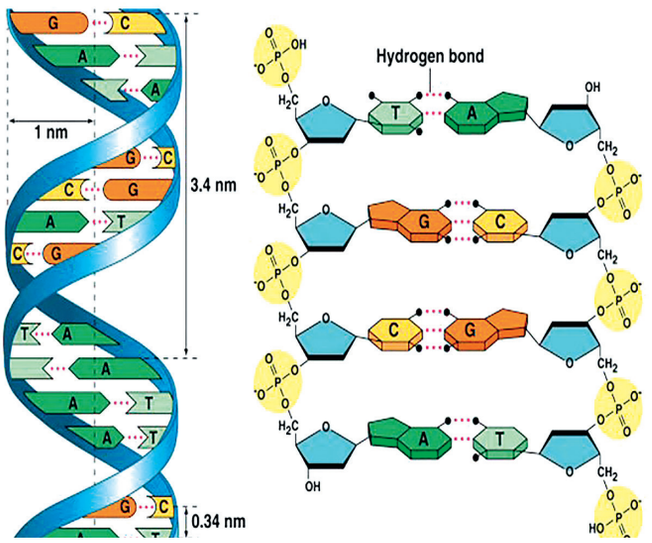

Figure 2: the double helical structure of DNA.

the risks and benefits of carrying out such a project. However, it wasn't until 1988, that The National Academy of Science gave permission for the HGP to begin.

The HGP was a large, collaborative, international effort. Driven entirely by a thirst for knowledge, it was unique in its approach. Specifically, no primary hypothesis was put forward and the data gathered was accessible to all involved.

Commencing in 1990, the project set out to sequence a map of the human genome and other carefully selected non-human organisms. However, this undertaking was by no means an easy feat. After all, humans have 23 pairs of chromosomes, containing approximately 25000 genes, made up of 3 billion base pairs of DNA.

Initially relying heavily on Sanger sequencing, the project began slowly in a somewhat cumbersome manner. However, as genomic technologies began to evolve, the enterprise gathered momentum, eventually reaching completion in 2003, two years ahead of schedule.

To emphasise how technologies can evolve, The HGP took 13 years to complete and cost close to one billion dollars. Today, using contemporary biotechnology; the human genome can be sequenced in 2 weeks at a cost of less than $2000.

Over the last two decades, the HGP has revolutionised medical science, paving the way for new treatment modalities and facilitating the identification of disease. Today, genomic science is steadily finding a place in mainstream medicine, proving invaluable in the treatment and understanding of a variety of conditions.

Many diseases impacting humankind, are linked to mutations in DNA. The HGP has thus proved crucial in the identification and diagnosis of a variety of heritable diseases. With contemporary, standardised genomic maps, researchers have been able to compare the DNA of affected individuals with that of normal human DNA samples.

Through this process, the genetic mutations involved in diseases such as cystic fibrosis, breast and colon cancer, Type 1 Diabetes, Huntington's disease, and Fragile X syndrome, have been identified. In fact, the precise mutation for Huntington's Disease – shown in Figure 3 - were identified as a direct result of the HGP. With a triplet repeat sequence (CAG) on chromosome 4 recognised as being responsible for the condition.

As technology continues to advance, increasingly complex conditions involving numerous genetic mutations, are now being elucidated. With the evolution of biotechnology allowing for diseases with multiple gene variants, such as Type 1 Diabetes and Alzheimer's disease to be identified. Consequently, pre-emptive lifestyle measures such as regular medical surveillance, diet and drug therapy can be implemented, all with the hope of changing the course of disease.

At present in Australia, in most cases, genomic testing can only be conducted if an individual has a strong family history of a particular condition, and consents to investigation. However, as technology evolves, it is likely this scope will expand.

As molecular medicine has evolved, scientists have been increasingly able to identify genetic sequences which predict drug responsiveness and metabolism. Consequently, genomic testing has been utilised to tailor specific drugs to individuals. In Australia, gene based 'designer drugs' have been utilised to optimise the treatment of hypertension, depression, schizophrenia, and diabetes mellitus. The hope being, that contemporary pharmacotherapy will target not only disease, but unique metabolic differences between individuals, in turn, enhancing drug responsiveness.

Genomic medicine has now been utilised to assist clinicians in optimising the treatment of a variety of cancers, with scientists comparing mutations in cancer cells to those of normal DNA. This allows for better categorisation of cancers and subsequently, more targeted treatment. For example, patients with breast cancer who possess the BRCA1 or BRCA2 gene, respond very well to a medication called Olaparib - the world's first cancer drug targeted against genetic mutations. However, this same medication is ineffective in those with tumours which do not possess these genes. Targeted drug treatments for melanoma and acute myeloid leukaemia are now also routinely used.

By undergoing genetic testing, patients with cancer can avoid ineffective treatment options. In many cases they are therefore able to avoid costly and at times dangerous invasive procedures. As molecular medicine continues to evolve, there is little doubt that more cancers will be responsive to targeted therapy. As a result, minimising the negative impacts of ineffective treatment for patients and society.

Over the last decade, rapid progress has been made in identifying genetic mutations linked to specific disease. Consequently, there has been a push to integrate genomic medicine into mainstream clinical practice.

The long-term goal is for patients' genomic data (likely obtained at birth) to be integrated into their general health record. Consequently, potential risk factors and mutations predictive of disease, could be identified and treated accordingly. This in turn would have the potential to and potentially prevent the onset of illness and prolong life. In addition, the economic benefits would be substantial.

Scientists have also highlighted the importance of constructing national and international data sharing platforms. This would enable specific mutations to be searched for in 'real time' and thus clinicians to obtain essential data while consulting.

The benefits afforded by genomic medicine are numerous and tantalising. However, questions remain regarding its safety and potential for harm. Particularly, if clear boundaries are not set around its use and access. In fact, many scientists have voiced concerns around the privacy of genetic information and posed the question; should a public database be put in place?

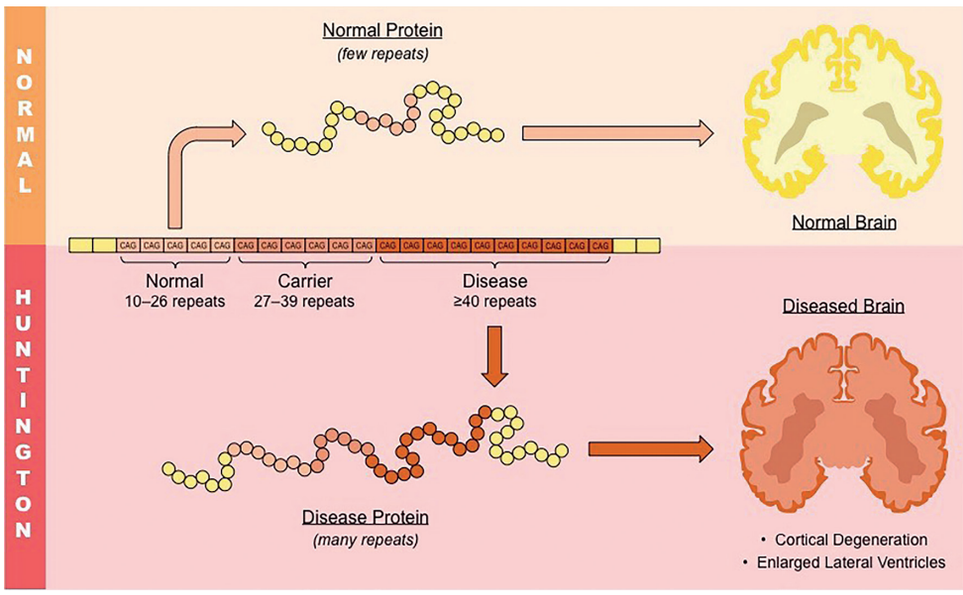

Figure 3 – Huntington's Disease from multiple (>40) CAG repeats on chromosome 4

Furthermore, very real fears exist around an individual obtaining access to their genetic information. Hypothetically, this could have the potential for human beings to believe their 'fate was sealed' at birth, so to speak. While an individual's genetic information is no doubt of supreme importance; it is by no means the entire picture. This concept has been highlighted by the film industry, with dramas such as 'Gattaca', presenting a bleak view of a world where genetic discrimination is rife. As genomic medicine continues to advance; established protocols must be implemented to ensure that the potential for harm is mitigated.

There is no denying that the evolution of the Human Genome Project has profoundly changed the face of medical science. Revolutionising the characterisation of disease, facilitating targeted drug therapy, and transforming the treatment of conditions such as cancer.

There is little doubt that the next decade will bring with it unprecedented advances in genomic medicine – a direct result of the most wondrous and intelligent map ever created by humankind.

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The Future of Batteries

Words by Charles Tang (Year 8)

Chemistry

Lithium-ion batteries are the most used batteries. however, they do not come without their flaws. Lithium-ion batteries require high amounts of water, placing stress on nearby freshwater bodies. Another common part of Lithium-ion batteries is cobalt, which is a difficult resource t extract from the earth and this process can devastate surrounding towns. However, alternatives are appearing like graphene-aluminium and sodium-ion batteries. But first, we need to understand how lithium-ion batteries work.

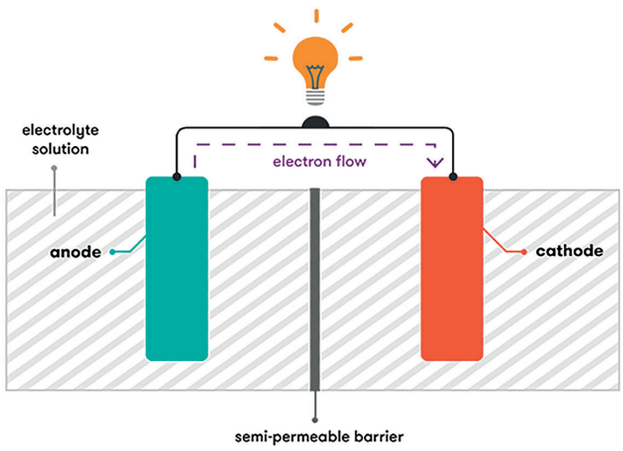

Figure 1: An electrochemical cell

A battery is defined as a device that stores chemical energy that converts it into electrical energy. This process is conducted in an electrochemical cell which is a device that can generate electrical energy from chemical energy or vice versa. Electrochemical cells generally have a cathode, anode and an electrolyte (see Figure 1).

Simply, electricity is the energy produced by the flow of electrons. To produce a flow of electrons, it is essential to have somewhere for the electrons to flow from and to. The electrons flow from one electrode, the anode (or negative electrode) to the other electrode, the cathode (or positive electrode). The anode and cathode are usually different metals or chemical compounds. The anode reacts with the electrolyte, the component that carries ions back and forth between the cathode and anode, producing electrons. While these electrons accumulate at the anode, the cathode undergoes a different process to accept these electrons. The reaction involving the exchange of electrons is referred to as a reduction-oxidation reaction (a redox reaction). A redox reaction can be split into two separate reactions, one occurring at the anode and the other at the cathode. Reduction is the gain of electrons; this occurs at the cathode; we say that the cathode is reduced during the reaction. We say that the anode is oxidised when it has lost electrons.

To maximise the efficiency of an electrochemical cell by using two different conducting materials with a significant standard potential difference (a substances tendency to gain or lose electrons). The ideal anode would have a much lower (negative) standard potential than the cathode. An electrochemical cell's overall electrochemical potential is determined by the difference in standard potential between the electrodes. The electrochemical potential is the force that the electrons will travel at between the electrodes and determines the cell's voltage. Voltage is defined as the electrochemical potential between two points. The greater the standard potential difference is, the greater the electrochemical potential is and the higher the voltage. When the standard difference is larger, the electrochemical potential and voltage will also be larger.

A battery's voltage can be increased by changing the materials to get a higher standard difference or by stacking multiple electrochemical cells. When multiple cells are combined in series, it affects the battery's voltage additively. Essentially, the force at which the electrons move at from the anode of the first cell to the cathode of the last cell would be seen as the force of the battery. Cells combined in another way (in parallel), rather than increasing the voltage, it increases the battery's possible current, the rate at which the electrons flow through the cell.

Another part of a battery is the electrolyte. An electrolyte must allow the movement of charged ions but should not conduct electricity. As negative electrons are sent through the circuit, a way to balance that movement of charge is necessary. The purpose of the electrolyte is to provide a medium that positive ions can flow through.

To maintain a neutral charge balance on the electrode while at the anode, the chemical reaction produces electrons, a matching amount of positively charged ions are produced at the cathode. The ions do not flow through the external wire (only for electrons) but are released into the electrolyte. Similarly to the anode, the cathode must also balance the charge of electrons it receives so the reaction that occurs here draws in positively charged ions from the electrolyte (alternatively, negatively charged ions from the electrode are released into the electrolyte). Ultimately, the electrolyte provides the pathway for the positively charged ions to balance the negative flow while the external wire provides the pathway of the flow of electrons. The role of the electrolyte is necessary to maintain the reaction.

There is a semi-permeable barrier to prevent ions moving with complete freedom within the electrolyte. This would cause the surfaces of the electrodes to be coated, clogging the system.

While the battery is used, new chemical products are produced by both electrodes. The product of the reactions at both electrodes can create a kind of resistance that lowers the efficiency of future reactions. As the resistance builds up, the reactions slow down and the back-and-forth electron war between the cathode and anode slows down, eventually losing its strength. The electrons stop flowing and the battery goes flat.

Lithium-ion batteries are very good at providing short bursts of high voltage, so we have developed a strong dependency on them, with them being used everywhere from consumer electronics, storing grid-scale electricity and electronic cars. Lithium-ion batteries have become the world's most common battery because they are lightweight and can be more compact than other batteries with some now recharging in as little as three minutes.

However, the extraction process of lithium is problematic, large underground deposits being pumped to the surface, resulting in around 70 000 litres of water being used just for one tonne of lithium. Nearly half the Earth's lithium deposits lie in Argentina, Bolivia and Chile. Mining Lithium consumes over 65% of an already scarce water supply. A large-scale 2021 study conducted by Wetlands International concluded that the mining of lithium poses a significant threat to the deteriorating wetlands through the substantial quantities of water vital for lithium mining and the salination of bodies of freshwater.

Another commonly used material in lithium-ion batteries is cobalt, which is expensive and is mostly mined in the Democratic Republic of Congo (DRC). The mining of cobalt has been exposed for using child miners and devastates local communities (see Figure 2). Cobalt has been found to be damaging landscapes, polluting water and contaminating crops. In streams surrounding the mines, wildlife has rapidly declined, being poisoned by acids and wastes from the mines. A study of the Tshangalale Lake, which is adjacent to mining towns, found that the fish were contaminated with notable levels of cobalt. The risk of this contamination spreading to locals is high through the consumption of these fish and the lake's water. The hazy air surrounding the mines has been confirmed to be full of dust and grit, ultimately being toxic to breathe. The risk of birth defects such as limb abnormalities and spina bifida has also been found to be greatly increased when a parent worked in a cobalt mine.

We need our batteries to be more sustainable. To help solve this conundrum different anode and cathode materials could be utilised. Sodium is a straightforward alternative for lithium because not only is it chemically similar to lithium, being in the same group on the Periodic table but also a thousand times more abundant, 20-40% cheaper and has no risk of blowing up due to temperature changes. However, compared to lithium, sodium has a lower energy density so batteries would have to be much heavier. Another issue with sodium-ion batteries is that their electrodes have been found to degrade much faster than those in lithium-ion batteries, ultimately reducing the applicability of sodium-ion batteries. This means that sodium-ion batteries will not be as cost-effective as lithium-ion batteries in the long run.

However, there is another metal that could replace lithium - aluminium. Aluminium batteries do not require rare earth metals and can charge even faster than lithium-ion batteries. In future, aluminium based batteries would also be easier to recycle. While aluminium-ion and lithium-ion batteries are conceptually similar, there is one main difference; aluminium can exchange three electrons for one ion while lithium can only echange one. The higher number of electrons per ion suggests a higher power density and capacity. This gives aluminium batteries a high theoretical volumetric capacity of 8046 mAh/cm3, about four times greater than lithium, being at 2062 8046 mAh/cm3. Aluminium-ion batteries also would not face some of the same environmental and social issues as lithium; they will safer, potentially cheaper and have low risks of flammability.

The Australian company, Graphene Manufacturing Group (GMG), has been given access to the University of Queensland to help them commercialise the aluminium-ion batteries. The graphene-aluminium battery works in a similar manner to a standard lithium battery. GMG uses a plasma technique to create graphene layers so closely layered that the aluminium

Figure 2: Children mining cobolt in the DRC.

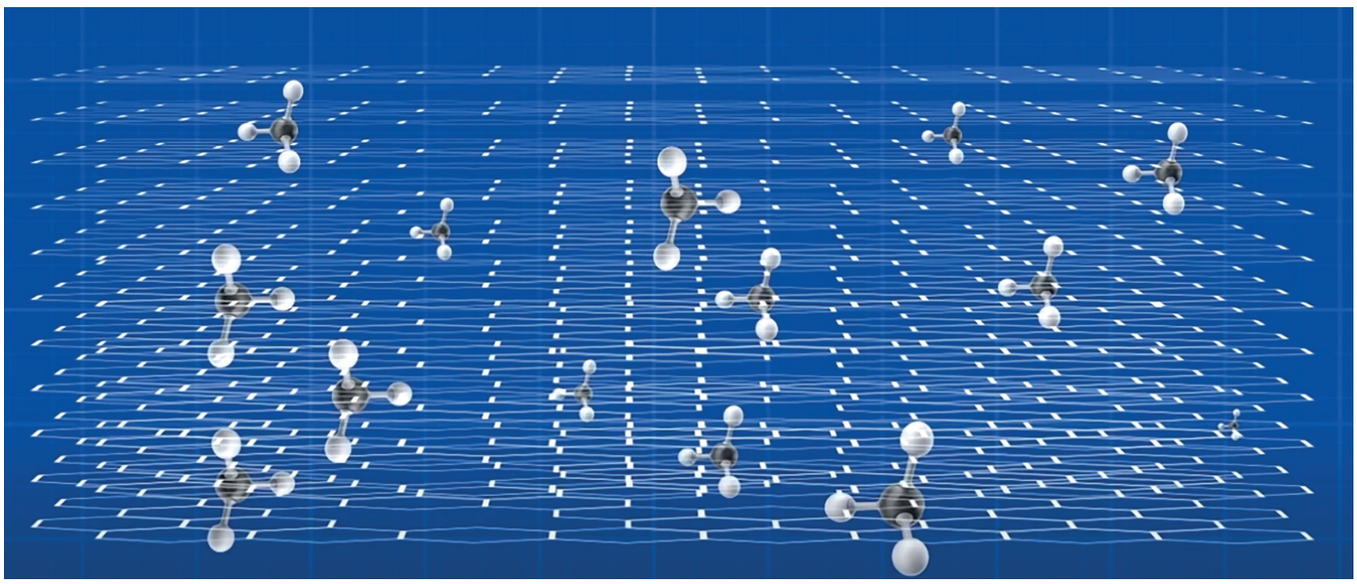

Figure 3: Holes are drilled into the carbon layers that the $AlCl_3$ molecules sit in.

chloride molecule ($AlCl_3$) they use cannot fit in between the gaps because they are 5.5 nm small while the gaps in between the layers of graphene which is about 0.3 nm. To get the $AlCl_3$ molecules inside the graphene layers, they essentially drill tiny holes for the $AlCl_3$ to sit in (see Figure 3). According to GMG, these batteries have achieved a charge rate of up to 70 times the rate of a lithium-ion cell. However, GMG is still developing their aluminium-ion battery but plans to start producing pouch cells for the electronic vehicle market by 2024.

While lithium-ion batteries are the most common batteries today, they are likely to be overtaken by other types; aluminium-ion and/or sodium-ion batteries. While the future of those batteries is promising, it is still important to remember that they are still in the pilot stage of their development. More time is needed. However, we cannot wait forever due to the withering effects from the extraction of lithium and cobalt. Our current needs for batteries have driven the innovation for them to be not only sustainable and have a high-power density but also ones that have longer lifetimes.

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Hydrogen Power; is it a useful pursuit?

Words by Aryan Parwal (Year 10)

Chemistry

The global pursuit of sustainable and clean energy sources has propelled hydrogen power into the spotlight as a promising solution. Hydrogen, the most abundant element in the universe, holds great potential as a versatile and efficient energy carrier when in diatomic molecules. This article explores the chemistry background, source of hydrogen gas, and pros and cons for hydrogen power along with an insight on the future prospects this bountiful element. The demand for renewable energy sources has never been more crucial. A promising option for decarbonizing a variety of industries, including transportation, business, and electricity production, is hydrogen power.

The process by which hydrogen gas and oxygen in a fuel cell combine chemically to produce energy and water is known as a hydrogen fuel cell. Hydrogen is fed to the anode, and air is fed to the cathode. In a hydrogen fuel cell a catalyst at the anode facilitates the oxidation of hydrogen molecules into protons and electrons, which take different paths to the cathode. The electrons go through an external circuit, creating a flow of electricity. The protons combine with the reduced oxygen ions to produce water (Figure 1). The electricity generated is then transmitted to motors that power various types of vehicles including cars, buses, and trucks.

The production of hydrogen is considered to be a more complex process than other means of renewable energy, but this is less significant when the uses of hydrogen become apparent. Hydrogen gas can be produced through various methods, including electrolysis, steam methane reforming, and more recently biomass gasification. Steam methane reforming is when hydrogen gas is produced from a natural gas, methane. This method is expensive and produces carbon dioxide. Electrolysis involves separating water into oxygen gas and hydrogen gas with the use of an electrical current. Although the source of this electrical current is unlimited, natural gas-powered facilities are currently the most prevalent way to produce energy. The only totally carbon-free method of using hydrogen fuel cells is to power the electrolysis process using solar or wind energy, both of which are not readily available in some parts of the world. Utilising hydrogen fuel cells is more expensive than other kinds of energy production because of how difficult it is to produce hydrogen fuel.

When hydrogen power first gained popularity in the 1990s and early 2000s, many people believed it would spark a clean energy revolution. However, this envisioned new world of

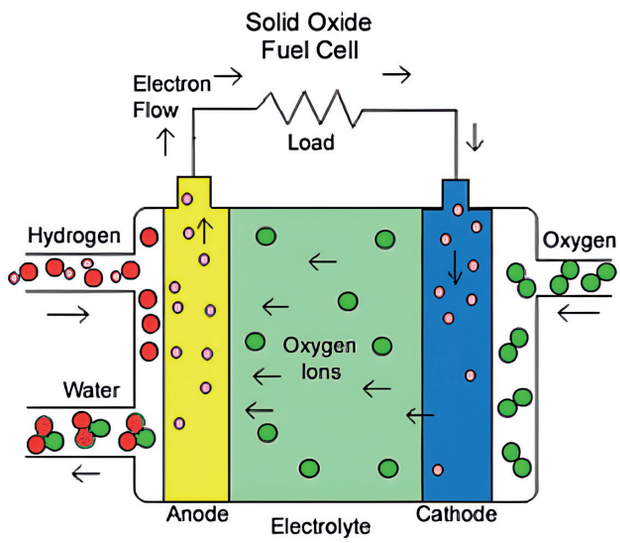

Figure 1: A hydrogen fuel cell.

hydrogen energy never came to be. Infrastructure is one of the main obstacles facing most new energy sources. Hydrogen fuel cells haven't been widely used as a technology for automobiles because of its high manufacturing costs, subpar production, manufacturing efficiency and challenging storage and transport requirements. But for those who can afford the necessary infrastructure, the hydrogen fuel cell makes more sense for industrial purposes.

High energy consuming appliances and vehicles are the most favourable items to rely on hydrogen power. Not only can such a large supply fulfill the energy requirements but using hydrogen will result in carbon emissions to decrease. The refuelling process for hydrogen fuel cells is easy and takes about three minutes, compared to the longer and more complex process of changing out a large, heavy lead acid battery when it needs to be charged.

Internal combustion engines are less energy-efficient than fuel cell vehicles (FCV). The efficiency of typical internal combustion engines is 20–30% while that of FCVs reaches a maximum of 60%. All vehicles use batteries to store energy. Lithium-ion batteries, with a CE ratings at 99%, continue to be the most effective and high-performance energy storage over lead acid batteries (9% less). While FCVs lose energy in the well-to-tank process (discussed below), they only lose 2% during tank-to-wheel, based on a study by the Copenhagen Centre on Energy Efficiency (Figure 2).

Based on Figure 2, battery electric vehicles offer the most efficient way to power a vehicle, assuming the best-case scenario of high efficiency rates throughout the entire process. Due to energy losses and inefficiencies, even if a fuel cell car may be able to travel further on a full tank of hydrogen than a battery-powered vehicle, the cost to fully charge the tank is higher. Hydrogen has a little more than a 3-fold higher cost per kilometre as compared to electric vehicles. The price per kilometre will be further impacted by additional expenses like building expenditures and hydrogen station profits (Table 1).

While it is true that hydrogen fuel cells don't release any dangerous gases when they are in use, this is not the case throughout the process of producing hydrogen gas. In fact, hydrogen energy is almost energy-neutral, which means that

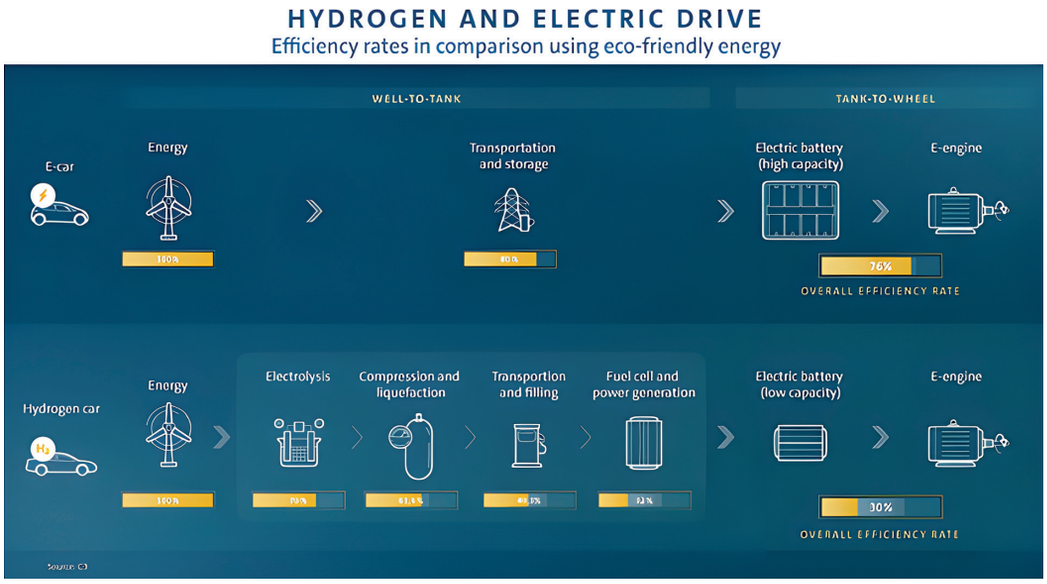

Figure 2: E-car and hydrogen car comparison

Comparative costs of running electric and hydrogen cars

	Electric Tesla Model 3 (75kWh)	Hydrogen Toyota Mirai
Price to fully charge or fill	15€	47.5€
Range (km)	499	502
Price/km	0.030€	0.095€

Table 1: A comparison betweel an electric vehicle (Telsta Model 3) and a hydrogen fuel car (Toyota Mirai).

the energy required to manufacture it is almost equal to the energy it generates. Using an emission-free energy source to generate hydrogen gas is essential.

Most fuel cells require hydrogen in the gas form, which can be kept in high-pressure tanks or kept as a liquid at cryogenic temperatures. There is a waste of energy inherent in both hydrogen storage techniques. About 13% of the hydrogen's total energy must be expended in compression, and about 40% must be lost in liquefaction. Highly flammable and easily containable hydrogen gas can escape. Hydrogen gas can damage metals if it escapes its containment. These tainted metals may then become brittle thus more likely to break as a result. Companies that now use hydrogen power can either have hydrogen gas brought to them through tube trailers for lower quantities or they must construct a plant on-site to manufacture hydrogen gas if they need a bigger quantity of fuel. This requires a large capital investment to set up the infrastructure needed for using hydrogen fuel cells.

Recently Rowan Atkinson was seen driving a Hydrogen power Toyota GR Yaris (Figure 3). This turned many heads as the car had retained its original 1.6L Turbocharged 3-cylinder engine but had altered the fuel supply, injection system, and engine management system of the car to burn hydrogen fuel.

Figure 3: Hydrogen powered Yaris.

This technology allowed for quicker development and rapid production for hydrogen powered vehicles as small alterations have to be made of existing ICE vehicles to be able to switch to hydrogen fuel.

In summary, while hydrogen is rapidly developing into something which could turn out to be sustainable, it does not seem both feasible and possible to sustain multiple aspects of our current lives on hydrogen energy.

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Sedimentation Transformed into Biodiesels and its uses in Society

Words by Hamish Searles (Year 12)

Chemistry

Biosolids are a useful product of wastewater treatment processes and are formed by separating the solids and liquids from recycled sedimentation. The solids are then physically and chemically treated to produce nutrient-rich biosolids which are commonly composed of a combination of water and organic matter. The desired elements held within the material are the macronutrients and the micronutrients which are key in improving the sustainability of agriculture through the presence of nitrogen and phosphorous for the implementation of fertilisers. Approximately two-thirds of the biosolids produced within Australia are applied to agriculture, as soil replacement, soil conditioner or the primary motivation for the production, fertilisers. In ancient times, manure was the most logical option when being applied as fertiliser due to the discovered high concentrations of the nitrogen-15 isotope. The fundamental concepts being explored within this analysis are the applications and limitations of biosolids in improving sustainability within agricultural systems, and the social, economic, environmental and ethical influence in society's acceptance in implementing biosolids as fertilisers within agricultural land.

The two major establishments of biosolids originate from both sewer sludge and recycled sedimentation, hence, the material's secondary disposableness property. Public water systems use coagulation, flocculation, sedimentation, filtration, and disinfection as a series of treatment stages to create potable water (figure 1). Coagulation involves the addition of positively charged chemicals which neutralise the negatively charged particles in the dirt and create larger particles. Flocculation then mixes the substance in a gentle manner to form heavier, larger particles, also known as flocs. Once settled, the flocs are removed through sedimentation, leaving a 'sludge' at the bottom of the water, which is commonly recycled into biosolids. To begin the process of generating biosolids, the sludge is chemically and physically treated, prior to the commencement of the biosolid management procedure. This begins with the dewatering of the material, the goal of which is to remove the water within, thus decreasing the substance's volume. The techniques used to remove the liquid include vacuum filtration, filter presses and sand drying beds however, after this, biosolids may still contain up to 70% water. Even with this, the subsequent material has improved manageability and reduced handling costs. Finally, stabilisation is instigated to reduce the pathogens within the biosolid substance and the potency of its odour, and the remaining substance is stored in treatment plants prior to use. Research illustrates that per tonne, biosolids contain approximately 4% nitrogen and 2.5% phosphorous, which are necessary macronutrients in agriculture. Alongside micronutrients, biosolids can be implemented as an effective fertiliser, therefore, reducing the quantity of chemical amendments used within farming.

The implementation of biosolids as fertilisers within agriculture has various positives not only for general farming but also on improving sustainability within agronomy. One of the most apparent impacts in which biosolids have when applied to agriculture is the presence of nutrients in which are essential for positive plant growth and development. The substance provides the flora with nitrogen and phosphorous which are essential, at a relatively low economic and environmental cost. In comparison to any chemical fertilisers on the market, biosolids are comprised of a wide range of necessary trace

The human stomach is acidic enough to dissolve razor blades.

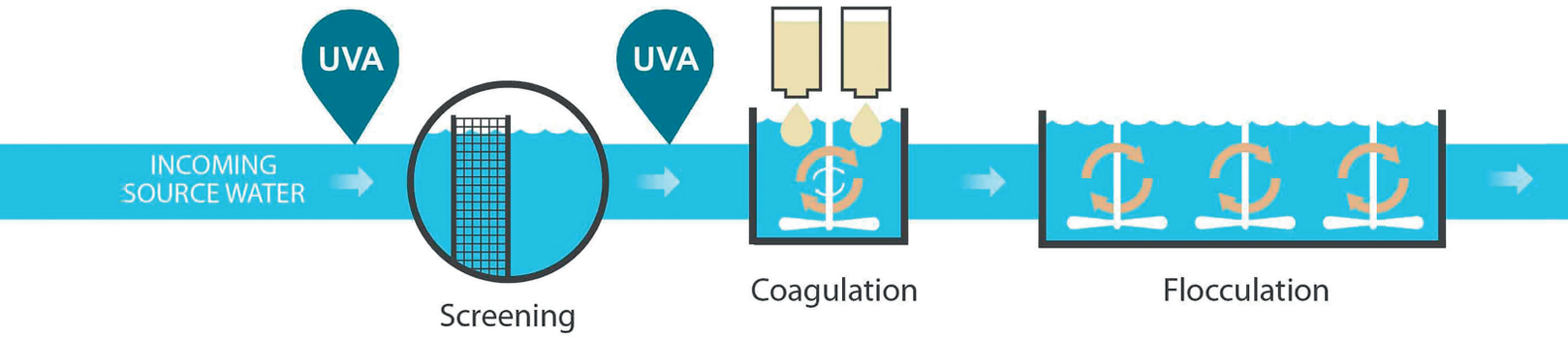


Figure 1 - Five stages of treating water

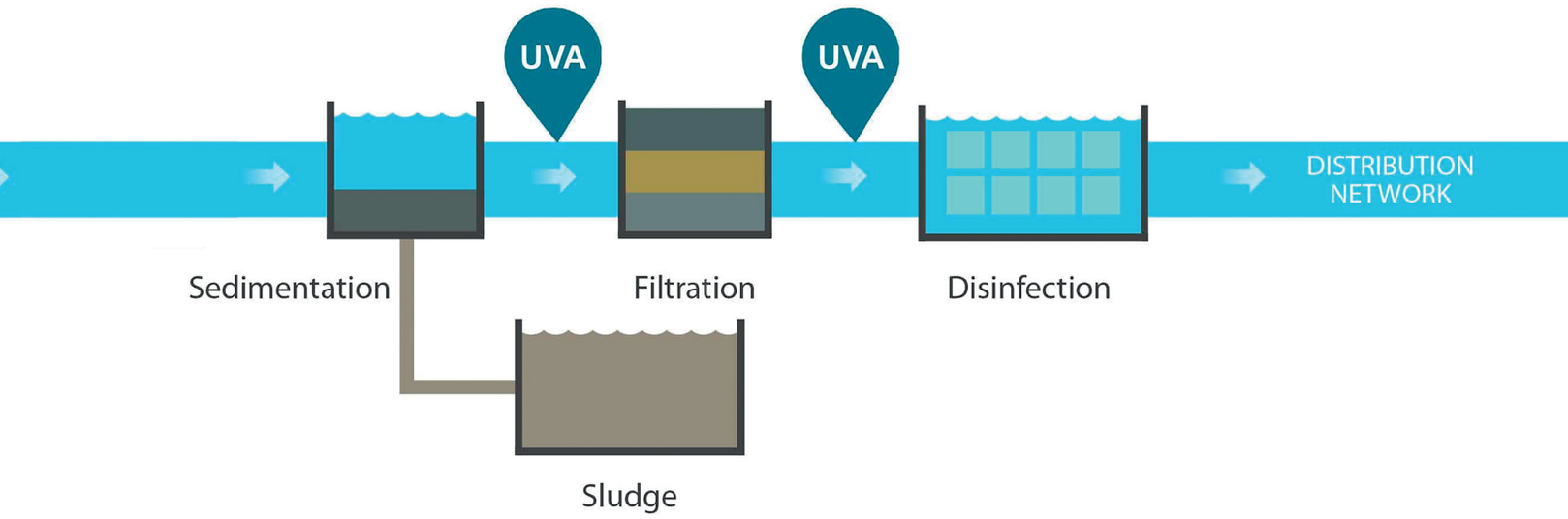
nutrients, and a chemical fertiliser blend of all nutrients present would be extremely costly to acquire. As a result of the high potency of heavy metals, the substance exceedingly increases the yield of crop, due to the nutrients improving the health of the soil in which crops grow, allowing for increased food quantities for humans. Furthermore, the soil quality is enhanced by biosolid's ability to store and absorb moisture from rain, as well as reduce soil erosion due to their characteristic of binding with soil particles, hence, retaining increased nutrients and lowering the effects of droughts and need for irrigation. Finally, in comparison to chemical fertilisers, which produce greenhouse gases, worsening the enhanced greenhouse effect, biosolids not only produce minimal greenhouse gases, but because of their ability to collect carbon in the soil particles using soil organic carbon sequestration, it postpones the emission of carbon dioxide, hence, also delaying its consequences.

However, certain limitations also arise when implementing biosolids rather than more traditional chemical fertilisers such as damaging local plant growth, arising health issues in neighbouring communities when applied and the excess additional nutrients. Although heavy metals enhance the growth in crops, research has found traces of unwanted metals such as nickel, lead and mercury which damage flora development. Another issue that has become apparent as farmers prioritise biosolids over chemical fertilisers is the potential of applying excessive amounts of nutrients. Too much nitrogen could potentially kill animals which attempt to eat the plants and surrounding vegetation, and surplus phosphorus accumulates within the soil and pollutes the underground water. Finally, although the substance treatment is a thorough and extended process, pathogens may still be present, and lower cost biosolids may be unfavourably treated. Therefore, when the negative effects of employing biosolids in agriculture became more evident after a study by the University of North Carolina indicated that 75% of residents who lived close to farms that used biosolids as fertiliser experienced health problems, the clear issues with the products safety in application were highlighted to public eyes.

The public found it difficult to accept the use of biosolids within our agricultural community because of the ethical and environmental impacts not only on human safety but other fauna and flora present on farmland. Over time, society has been finding it hard to acknowledge the growing use of biosolids within farms, due to the social issue of allowing people who live nearby to land which implement the fertiliser to develop illness. David Gattie, working for the US Environmental Protection Agency, conducted a study which explored the association between class B biosolids and health issues experienced by adjacent residents, and the results conveyed that people within one kilometre experienced skin and eye irritation caused by the winds blowing particles across their land. In 2019, approximately 60% of biosolids produced by treatment plants will be on farming land, therefore, people are getting worried about the health and safety risks involved with the substance and neighbouring residents. The substance has further been found to not only cause illness but contaminate drinking water and hurt livestock (especially when excess biosolids are added to crops). Therefore, people are calling for a ban on the organic material on farmland until a safer alternative can be created. This in conjunction with the potent odour the substance emits (which the public sees as an additional health risk) have become social issues that must be considered prior to the use of the material as fertilisers over the chemical variety.

However, when considering the usage of the substance, the significant environmental and economic benefits of biosolids in agriculture such as the cost effectiveness of the product and reduced enhanced greenhouse effect must be considered. Due to the secondary disposability of the substance (every ingredient is recycled from sedimentation and sewer sludge), the material is extremely viable economically because the only costs needed for production is energy and machinery within treatment plants. Furthermore, in comparison to chemical fertilisers which only provide nutrients, biosolids produce nutrients, organic matter and trace metals, all of which positively impact crop growth. Due to the unsustainable nature of chemical fertilisers, explained by the environmental runoff causing significant greenhouse gas emissions, it is critical to apply biosolids to reduce the environmental cost, whilst also stabilising the effectiveness of the soil stimulants. Biosolids save at up to 6 tonnes of released carbon dioxide equivalents when compared to inorganic fertilisers utilised in agriculture due to its ability to store carbon within soil particles. In addition, the production of biosolids only burns limited fossil fuels in treatment plants for energy, whereas chemical fertilisers need increased energy for production.

Ultimately, not only is the application of biosolids as organic fertilisers on agricultural land a significant step from an environmental perspective, it also improves crop growth efficiency and yield. Evidently, use of biosolids has numerous positives including lowering greenhouse gas emissions created through their production compared to chemical fertilisers, their ability to store carbon, and the mass amounts of ingredients they contain to improve crop production. However, unwanted metals, potential pathogens and pollution from its components also limit their use in society. Therefore, prior to converting the majority of worldwide farms from inorganic fertilisers to biosolids, the world must consider possible social and ethical issues involving people's health from use of biosolids against



the environmental positives in creating a more sustainable farming community. Overall, although biosolids could potentially diminish climate change impact of one of the major anthropogenic sources of greenhouse gases in agriculture, before implementation, society must weigh the positives alongside the negatives in replacing chemical fertilisers with a more organic alternative.

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Reversible addition-fragmentation chain-transfer (RAFT) polymerisation; a step towards genuine plastic recycling.

Words by Max Whittle (Year 11)

Chemistry

The widespread utilisation of plastic in our everyday lives is the stem of serious concern, and for justifiable reason. Plastic pollution is a global crisis, with an estimated 7 billion tonnes of the plastic produced from 1952-2017 ending up as plastic waste. Plastic waste has tremendously adverse effects on wildlife, functions as landfill, contaminates drinking water and food, and on top of this, the demand for plastic is ever-growing. Hence, the concept of recycling plastics is fundamental in reducing the prevalence of plastic waste. Reversible addition-fragmentation chain-transfer (RAFT) polymerisation has emerged as a viable method of recycling plastics through the formation of chain-end radicals which in turn evoke depolymerisation and the recovery of monomers for future use.

Polymers compose many of the materials found in everyday life, and importantly are the basis of all everyday plastics. Polymers are substances which are composed of repeating simple chemical units called monomers. Polymerisation describes the process in which monomer units chemically combine to produce a larger network molecule known as a polymer; the process involved in plastic production, whereas depolymerisation is the process by which a polymer is broken down into its respective monomer components. Hence, utilising depolymerisation, plastic polymers which otherwise would occupy landfill can be broken down into their respective monomer units. These monomers can then be recycled back into the plastic production process, utilising polymerisation to form an alternate and now useful plastic product. However, the ability of a polymer to be broken down into its constituent monomers is dependent on the method of polymer production used in the first place. In order to produce plastic polymers which are able to undergo depolymerisation and subsequent recycling, the polymerisation technique known as RAFT polymerisation is utilised, a process which produces polymethacrylates which are able to be broken down, whereby the high-end group fidelity of RAFT polymers can be manipulated to generate chain-end radicals at approximately 120 (see Figure 1).

A radical is an atom, ion, or molecule which possesses unpaired valence electrons and as a result these radicals

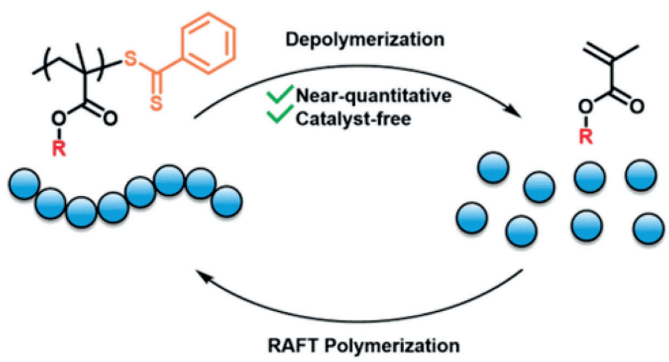

Figure 1; Diagram of RAFT polymerisation and the subsequent depolymerisation it enables

are extremely chemically reactive towards other chemical substances, and themselves. In this case, the formation of radicals evokes the unzipping of polymers, and thus the depolymerisation into constituent and recyclable monomers.

The impetus to depolymerise and subsequently recycle plastics has been influenced by the adverse environmental impacts associated with the mass-production of plastics. According to the United Nations, across the world, in excess of 400 million tonnes of plastic is produced every year, of which half is single use, and a mere 10 percent is recycled. Moreover, the vast majority of plastics utilised in day-to-day life are synthetic. Thus they are designed to resist natural decay processes and subsequently are nonbiodegradable, persisting in environments for years. Hence, plastic functions as a tremendous source of waste, not only occupying landfill but also polluting natural ecosystems. For example, approximately 23 million tonnes of plastic end up in waterbodies every year. Subsequently, the mass-production of plastics and the associated environmental consequences have stimulated the need to develop methods such as RAFT polymerisation that heavily reduce plastic production; recycling plastics and thereby limiting the need to continue the production of many single use plastics.

Moreover, the application of producing chain-end radicals for depolymerisation has been influenced by the drawbacks associated with the current processes of plastic depolymerisation. Many of the current depolymerisation processes are largely economically unviable in industry, especially when considering the scale of plastic use. This is due to the large energy requirements needed to break the covalent bonds between each monomer (which require temperatures in excess of 450, and hence convert a polymer into its monomer constituents. The large energy requirement of depolymerisation is the fundamental reason why it is not

a favourable process within the industry. A large energy requirement makes it a more cost worthy process than the alternative - producing new plastic 'from scratch' whilst disposing of the older plastic. This drawback of current depolymerisation methods has influenced further research and development on reducing the energy requirement of depolymerisation. Subsequently the production of chain-end radicals on RAFT polymers has been found to require much less energy, whereby the polymer solvent mixture must only be heated to 120. Thus, this decrease in energy demand has increased the industry and economic viability of recycling plastics through depolymerisation.

Despite the effectiveness seen in the recovery of monomers when producing chain-end radicals in RAFT polymers, a 92 percent recovery of polymethacrylate monomers, this method of inducing depolymerisation is only currently applicable to polymethacrylates, a small branch of plastic polymers. Thus, further work is being undertaken by a team of researchers at ETH Zurich to investigate if other polymers can be depolymerised utilising a similar process; the research into polystyrene, a common plastic with numerous uses in everyday life, has taken priority. Moreover, researchers aim to increase the recovery of monomers to 100%, and hence permit greater recycling of polymethacrylates. Ultimately, with the increasing economic viability of this technology as a means of recycling plastics, and the possibility of depolymerising a greater variety of plastics, producing chain-end radicals in RAFT polymers will undoubtably emerge as a vital process in combatting plastic pollution in the years to come.

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Your body produces enough heat in 30 minutes to boil half a gallon of water.

Technological Progress and Environmental Concerns on the Possible Applications of Lithium-ion Batteries

Words by Oliver Davey (Year 12)

Chemistry

Portable lithium-ion batteries have allowed the storage and use of energy in many things, from mobile phones to increasingly common electric cars. But, with the growing reliance on lithium-ion batteries across the world, their detrimental impact on the environment can now be seen, leading to a rising demand for more effective, efficient, and sustainable battery technologies for the future. Through recent scientific assessments, researchers have proposed an alternative to reduce the negative impacts of lithium-ion batteries. That is, using carbon-based electrodes that can be derived from carbon capture. However, the usage of these new technologies comes with unexpected consequences that must be addressed through assessment and further development, influenced by advances in other areas of science, as well as social, economic, and environmental factors that must be considered.

A lithium-ion battery, much like a typical galvanic cell, is made of an anode, a cathode, and an electrolyte. However, the charge from lithium-ion batteries is solely generated from the movement of lithium ions, which creates free moving electrons allowing an electrical current to be created (Figure 1). This process is reversible, and therefore a lithium-ion battery is rechargeable, unlike primary galvanic cells. When charging, the cathode (lithium-cobalt oxide) releases some of its lithium ions, which move through the electrolyte to the anode and remain there. This process stores energy for the battery to release through discharge. When discharging, the lithium ions back across the electrolyte to the cathode, releasing the stored energy and powering the battery.

Lithium-ion batteries, when compared to other alternatives, have one of the highest energy densities due to the low mass, but high reactivity, of lithium (Figure 2). In addition, they also can deliver a large amount of current to high-power devices, with comparably low maintenance. This makes lithium-ion batteries highly effective in modern technologies such as mobile phones and cars. However, batteries are relatively expensive to manufacture and use for energy storage over alternatives such as petroleum. Common metals present in

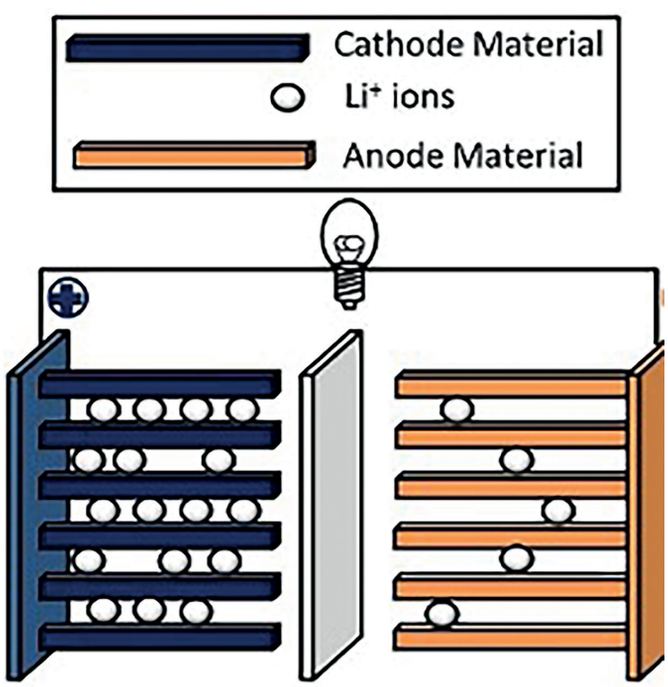

Figure 1: A general schematic of a lithium-ion battery

the cathode of a lithium-ion battery, including the highly priced cobalt and nickel, are discarded when disposing batteries, increasing the cost of lithium-ion battery production with the decrease in unsustainable precious metals. In addition, the incorrect disposal of lithium-ion batteries leads to precious metals leaking from the casing of the battery. This can contaminate the soil, seawater and fresh water supplies, poisoning ecosystems and people due to the metal ions causing damage to internal organs including the liver, brain, and kidney. Substituting the anode with carbon nanotubes can circumvent many of these issues, with fewer toxic by-products being released when disposed. The structure of carbon nanotubes leads to favourable properties when used as the anode, including a high surface area accommodating a larger number of lithium ions, and high electrical conductivity due to its layers of delocalised electrons (Figure 3). However, carbon nanotubes can still hold risks, as lithium ions could adhere to the outside of the carbon anode when at high power output, becoming a safety hazard.

With the exponentially increasing demand of electric transportation (Figure 4), larger and more efficient lithium-ion batteries are more desirable than ever. Commercial lithium-ion batteries have been in use since the 1990s and have taken

over other battery alternatives, becoming the dominant means of energy storage. At that time, lithium-ion batteries were solely used for low powered mobile phones and laptops and were not intended to be used to power large vehicles or industrial processes. The rapid advancement of the electric motor has demanded an equal advancement in battery technology that allows electric cars, trains, and busses to travel further and more efficiently. Electric car adoption has more than tripled between 2017 and 2020. This increase in consumer electric vehicle adoption demands the development of superior battery technologies, including the replacement of inefficient and costly lithium-based electrodes. This development has led to the application of Carbon-based lithium-ion batteries, with greater power delivery rates and energy outputs able to run more demanding transport technologies, including large trucks and heavy vehicles.

However, the advancements in battery technologies are also influenced by increasing tension surrounding environmental and economic issues. With the large number of lithium-ion batteries currently in use, it is expected that 11 million metric tons of lithium-ion batteries will reach the end of their service lives by 2030. This, combined with the number of lithium-ion batteries that go to landfill (less than 5% are recycled), has and will have a significant impact on the natural environment. The high rate of incorrect disposal of lithium-ion batteries leads to a large amount of metal being lost, with a lithium-ion battery's weight consisting of 30-40% valuable cathode metal which can be recycled. The effect of the strong social disregard for recycling lithium-ion batteries has forced alternatives to be developed, driving research to examine substitutes that are cost-effective and environmentally sustainable. This led to the possibility of utilising carbon capture to produce carbon nanotube-based electrodes critical for environmental sustainability. Using the solar thermal electrochemical process (STEP), ambient carbon dioxide can be removed from the atmosphere and used to manufacture carbon-based electrodes, providing a longer service life for lithium-ion batteries, and reducing the amount of precious material that is wasted when incorrectly disposed. However, this technique cannot be fully applied without the wide adoption of carbon capture technologies, limited by the cost of entry.

Lithium-ion batteries containing carbon-based electrodes allow a boost in power capacity and energy delivery when utilised over standard lithium-ion batteries, whilst having a less significant impact on the environment. Typical lithium-ion batteries hold many applications, being effective and allowing for large energy draw. However, the environmental cost associated with the use of lithium-ion batteries, specifically regarding disposal, significantly limits their sustainability. Researchers from the Massachusetts Institute of Technology (MIT) have developed an alternative to using purely lithium-based electrodes, instead substituting carbon nanotubes for the anode. In doing so, these batteries gain a boost in energy capacity whilst being able to maintain a high power delivery rate ten times greater than lithium-ion batteries. However, the development focusing on increasing power delivery holds unexpected benefits, as reducing the lithium metal required in the production of lithium-ion batteries reduces the impact of the environmental and economic limitations plaguing their sustainability. Introducing carbon nanotubes as a replacement

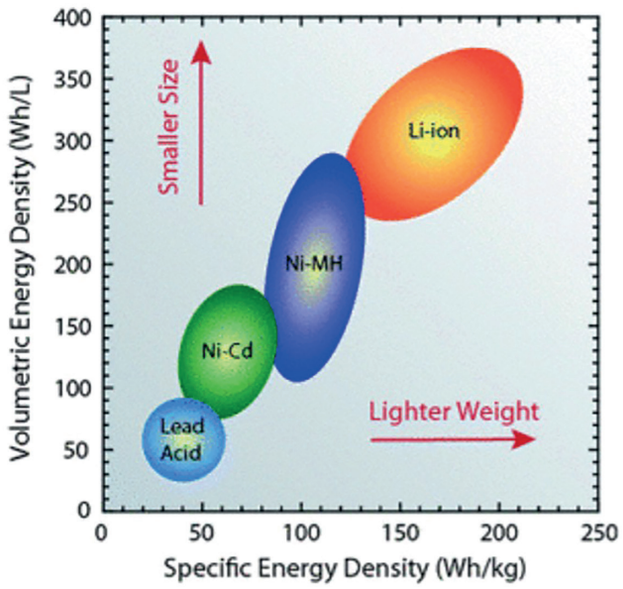

Figure 2: A diagram depicting the energy density and volumetric density of different battery types

for lithium electrodes would reduce the amount of lithium that leaks into otherwise healthy soil and water supplies caused by the incorrect disposal of lithium-ion batteries. The decreased amount of lithium required would also reduce the cost of manufacturing, encouraging more companies to implement more environmentally friendly manufacturing processes.

The adoption of carbon-based electrodes is limited by production and the requirement for economic investment. However, this leads to further technological development which both overcomes this economic limitation and holds further applications in environmental sustainability. As lithium-ion batteries are so widely adopted in various conditions, the production of lithium-based electrodes and electrolytes has grown to account for the increasing demand. The volume of production of carbon-based electrodes is too low to immediately and totally replace lithium-based electrodes. Therefore, for carbon nanotubes to become a universal component of lithium-ion batteries, monitoring of the production process of carbon nanotubes is required to allow

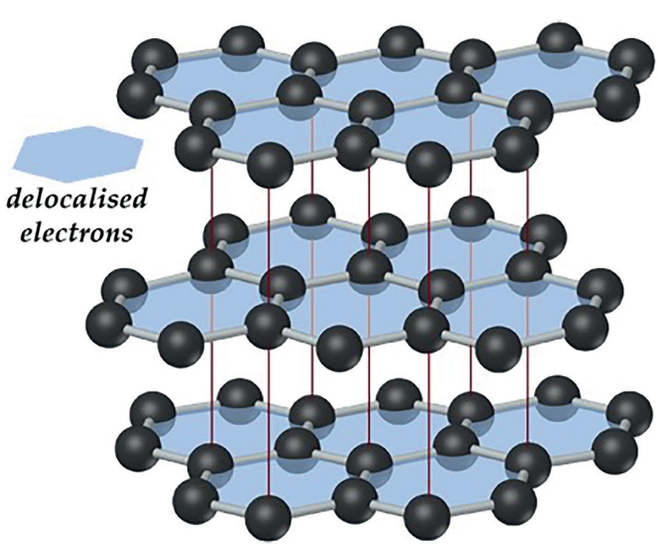

Figure 3: A representation of the delocalised electrons present within graphite, the material used to create carbon nanotubes

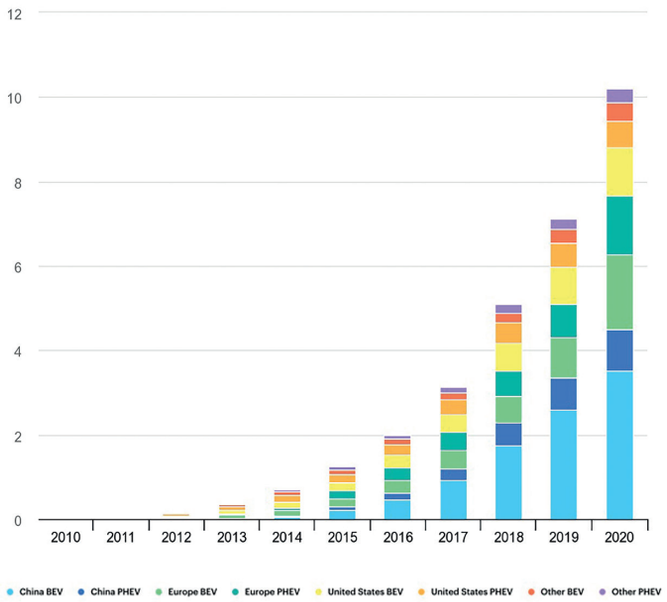

Figure 4: A graph of the global electric passenger car stock from 2010 to 2020 (in millions)

the growth of carbon nanotube production. However, through observing the economical limitations concerning the utilisation of carbon nanotube electrodes, scientists from the American Chemical Society (ACS) have discovered an alternative to the typical production of carbon-based electrodes. By utilising ambient carbon dioxide from the atmosphere, carbon nanotubes can be produced ethically and at a high volume. This innovation resulting from the evaluation of the limitations of carbon-based electrodes in lithium-ion batteries allows the more ecological use of modern technologies, reducing the environmental cost at all stages of use, from production to disposal.

The development and application of carbon-based battery technologies has universal benefits, with the possibility of reducing carbon emissions, increasing energy density and power output, increasing lifespan, and reducing cost. Though, these applications are limited by the need to increase carbon nanotube manufacturing technologies across the globe, and the need to monitor and assess the risks involved with producing a new technology. That, however, does not mean that carbon-based lithium-ion batteries should not be developed further, as the promise they hold in improving the quality of life and the environment is immense.

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AI is used in precision agriculture to optimize crop yields, monitor soil conditions, and even automate tasks like harvesting.

The utilisation of nanoparticles in microalgae biodiesel production

Words by Jack Dundon (Year 12)

Chemistry

The negative environmental consequences of fossil fuel use and their rapid depletion, has led to the need for finding a more sustainable and environmentally friendly solution. With global energy demand projected to increase 25% by 2040 extensive research has been undertaken on methods to convert biomass into biodiesel. First generation biodiesel was made from edible crops, second generation biodiesel from waste products, and now third generation is microalgae biodiesel (MABD). First and second-generation biofuels currently make up 99% of global biofuel production. Microalgae is an attractive energy source due to its high lipid concentration, rapid proliferation cycles, sequestration of carbon dioxide via photosynthesis and ability to thrive in harsh aquatic environments. The primary issue faced by MABD production is its high costs ($2.80/L) compared to traditional fuels ($0.48/L), which makes it not economically feasible However, MABD presents a promising option for biofuel production when enhanced by nanoparticles (), which have the potential to improve the efficiency, affordability and efficacy due to their unique properties.

Lipids are first extracted from between the microalgae's cell membrane and cell wall. The non-polar and lipophilic organic solvent, chloroform (CHCl3) or hexane (C6H14), diffuse across the phospholipid bilayer and the lipids dissolve into these solvents. However, this often decreases the cell membrane's structural integrity and commonly leads to cell rupture. This lysis is why the recultivation and restoration of the microalgae after harvest is so necessary. The glycoproteins and weak secondary interactions also increase the mechanical resistance between the solvent and the lipids, consequently decreasing the yield.

MABD is a biofuel produced through the base-catalysed transesterification of triglycerides from microalgae (see figure 1). Once the triglycerides are extracted, they are reacted with methanol using a strong base catalyst (often NaOH). The product is propane-1,2,3-triol (glycerol), and fatty acid methyl esters (FAMEs, or biodiesel). Transesterification is most commonly performed in an external vessel, however, can also be performed in situ.

The use of mesoporous nanoparticles, due to their pore size, enzyme carrying capability, surface area to volume ratio, absorption of lipids and tunability makes them an attractive new approach to MABD production. They are mixed into the reactants and usually added during the transesterification step, however, can be integrated within various stages of MABD to provide a range of different benefits. The mesoporous nanoparticles are most often silica or metal oxides, and are arranged in a honeycomb structure (see figure 2). These enzymes are catalytic due to their abundance of active sites which adsorb the reactants and facilitate the cleavage of the ester bonds in the triglyceride. The active sites deprotonate the alcohol molecules, increasing their reactivity for the subsequent transesterification reaction, whereby they break the triglyceride's carbonyl groups, desorbing afterwards so that the process repeats.

Although not essential, it is also advised that a 6:1 ratio of methanol and triglycerides is used so that stress is placed on the system and the equilibrium position shifts towards the forward reaction, consequently leading to an increase in the formation of biodiesel, according to Le Chatelier's Principle.

Alongside the improved reusability and recovery of nano-catalysts, by utilising a catalyst embedded in the pores of mesoporous nanoparticles, the conversion of microalgae to biodiesel can be streamlined by being performed in situ as opposed to occurring in an external vessel. This negates the requirement for multiple steps and complex equipment, therefore reducing the time, energy and resources needed.

The exceptionally large surface area of nanoparticles allows catalysts to be impregnated into them and thus more

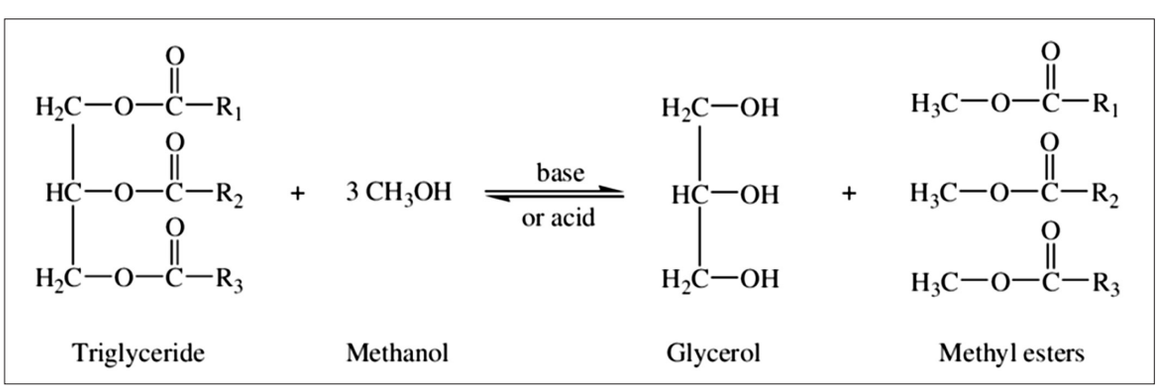

Figure 1: The transesterification process whereby the reagents; methanol and a triglyceride react with a strong base catalyst, to form FAMEs and propane-1,2,3-triol

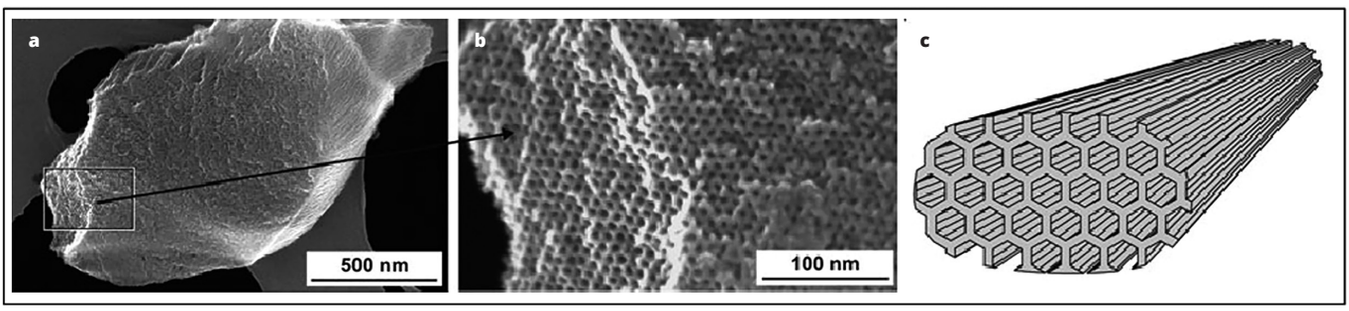

Figure 2: (a) An SEM micrograph showing a mesoporous silica nanoparticle, (b) a zoomed-in portion from the rectangular section marked in (a), and (c) a schematic diagram depicting the geometrical honeycomb structure of mesoporous silica nanoparticles.

efficiently absorb the lipids. Although the concentration of lipids in microalgae is over 200 times that of any other biomass, it was often unable to be effectively extracted, with yields as low as 15%. Nano-enhanced MABD yields can increase by up to 75%, with a calcium oxide nano-catalyst exhibiting a ten-fold increase in yield in comparison to regular sized catalysts.

A more effective lipid extraction inhibits the destruction of the cell, ensuring that a more continuous growth can occur without the need for re-cultivation. Given that extraction typically makes up 70% of production costs the decrease in water, light, fertiliser and time between extractions reduces expenses significantly.

Further advantages of using nanoparticles are that the burning rate, fuel lubricity, water solvency and unburnt hydrocarbon emissions of MABD all substantially improve. This demonstrates its contribution to the pollution prevention principles of Green Chemistry, and thus its superiority over regular MABD and the aforementioned fuel alternatives above.

Nanoparticle toxicity and their effects on the human body are a largely unknown and incomplete area of scientific understanding. Current research on nanoparticles in MABD has only been performed on a small scale, hence why full-scale implementation of nanotechnology in MABD production is deemed by many to be premature. Nanoparticles can elicit a series of harmful effects on humans, plants – aquatic and terrestrial - and other atmospheric creatures, such as oxidative stress, inflammation and a range of other symptoms and pathologies due to their size. For example, prolonged exposure to silica nanoparticles has shown to have a high correlation to lung disease. Workplace Health and Safety protocols must be enforced to protect the consumers of products and the personnel involved in the industry.

A further limitation of using nano-catalysts is that the enzymes, most often lipase, are very sensitive to pH and temperature. When these conditions are not in their optimal range, there is a considerable decrease in the efficacy of the biological catalyst. If the pH is outside of 6-8, the ionic bonding of the protein is altered, and thus shape of the protein becomes abnormal and therefore cannot catalyse properly. If the temperature is above 45oC, the increased kinetic energy of the protein molecules increases the vibrations and therefore disrupts the secondary interactions, inhibiting successful catalysis. In comparison to the optimal conditions for transesterification, the pH is 7-9 and the temperature is 50-70oC. Thus, a compromise must be met in order to balance yield and speed, hence why transesterification is often performed at 45oC and the pH between 7-8, slightly decreasing the rate of reaction to ensure the lipase remains effective.

The current economic feasibility of MABD is limited by the speed and costs of transesterification. These limitations influenced research into nano-catalysts as a way to improve the efficiency, performance and reusability of the processes.

The speed of transesterification is limited by free fatty acids (FFAs) reacting with hydroxide ions from the NaOH catalyst, causing a disruptive saponification reaction. This formation of soap neutralises the catalyst, therefore inhibiting the production of biodiesel. This discovery influenced scientists to urgently search for a solution, eventually finding that specific lipases when imbedded in silica mesoporous nanoparticles were able to prevent this saponification through the sequestration of the FFAs, which in doing so reduced the requirement for costly, intensive drying procedures, hence improving the efficiency and affordability of MABD production.

Another factor that limits the affordability of transesterification is the difficulty in the recovery of typical catalysts, influencing research into metal oxide nanoparticles which could then be collected using magnetic flocculation. It is a fast, energy efficient and low-cost procedure that eases the detachment of the magnetic nanoparticles and lipids from the algae, saving significant costs and improving the efficiency of the production as a whole.

The influence of politics has also been a significant factor in the research for nano-enhanced MABD. There has been large support in recent years by the USA, EU and China for MABD policies, as well as the countries involved in The Paris Agreement in their pursuit for more sustainable solutions. This large emphasis on Green Energy has influenced the use of nanoparticles in MABD production to be more cost-effective and efficient so that it is able to compete with other sustainable energy sources. The proponents who have supported MABD policies would be likely to assist during the eventual roll-out of MABD, and if they initially subsidised MABD and taxed traditional petroleum more heavily, this would significantly assist MABD in infiltrating the market. Demand would lift, and MABD plants would be able to increase their production to levels that will ensure the long-term practicality and affordability, improving due to economy of scale.

Overall, the prospects of nanoparticle enhanced MABD are very promising, and offer a cleaner, more sustainable alternative to traditional fossil fuels. The current trends in global warming, energy usage and population growth have catalysed the progression in 3rd generation biodiesel research, however a significant number of further studies must be

completed to mitigate any of the limitations associated with MABD before commercialisation. The affordability of MABD, toxicity of nanoparticles and the sensitivity of lipase, alongside uncertainties regarding government endorsement and commercial scale production are the cause for any reluctance associated with any impending MABD rollout. Nonetheless, nanoparticle-enhanced MABD's superiority over petroleum regarding its functionality, lipid concentration, efficiency, recovery and reusability, growth rates, sequestration of CO2, in situ transesterification and ability to thrive in harsh environments without a requirement of fresh water or land have garnered significant funding and optimism levels for the future development of MABD when enhanced by nanotechnology.

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The potential of FLASH Proton Therapy in addressing the limitations of conventional cancer treatment

Words by Don Bui (Year 12)

Physics

Radiation therapy has long been a crucial component of cancer treatment. With contemporary machinery, precise and highly conformal radiation beams can be targeted to minimize damage to healthy tissues surrounding the tumour. However, despite these advancements, complete eradication of cancerous tissues remains dose-dependent and limited by the potential for severe radiation-induced side effects. As such, the emergence of new technology in FLASH radiotherapy as a result of ongoing collaboration between different disciplines shows great promise in overcoming the limitations of conventional radiotherapy treatments. FLASH radiotherapy involves the rapid delivery of radiation at significantly higher dose rates than those used in conventional radiotherapy. Preclinical trials show evidence that delivering high dose rates through FLASH can enhance disease control whilst further reducing negative side effects. By verifying and reviewing the theoretical benefits of FLASH in clinical trials, the technique holds great potential in revolutionising the field of radiation oncology. However, despite the significant potential of FLASH radiation therapy, there are still many unanswered questions, and extensive multidisciplinary research is required to fully understand and utilise its capabilities.

As cancer cells quickly grow and divide, they are more susceptible to radiation damage compared to normal cells. When cancer cells are exposed to high energy, ionising forms of radiation, their DNA becomes damaged, hindering their ability to grow and divide. Ionizing radiation is utilized in cancer treatment as it forms ions in the cells of the tissues exposed to it, by removing electrons from the atoms thus changing the DNA and impeding cell growth.

Electromagnetic (EM) radiation, characterises the types of radiation used in cancer treatment. EM waves are comprised of oscillating electric and magnetic fields that are perpendicular to each other and the direction of the wave propagation. The vibrating fields emanate from the vibrating charge. Therefore, even after the charge has stopped accelerating, the changing fields keep recreating themselves and radiate from the original accelerating charge with a constant speed of 3×10^8 m/s. Different types of EM waves are produced by charges oscillating at different rates. As such, the frequency of EM waves is determined by the frequency of the oscillating charge that creates the wave. Hence, the frequency of the oscillation will characterise the type of EM radiation that is produced as seen in Figure 1.

The way each type of radiation behaves is an important consideration in radiation treatments. Types of radiation can be categorised as non-ionizing and ionising. Radio waves, microwaves, and visible light waves are types of non-ionizing radiation as they do not have as much energy, and are not charged, they are unable to form ions. The varying amounts of energy these waves possess dictates how deeply the radiation can penetrate tissue. Radiation used in cancer treatment is typically high energy ionizing radiation, such as X-rays or gamma rays. These have greater frequencies and therefore more energy, hence their ability to penetrate tissue.

Cancer is one of the most significant and widespread diseases in the world. It is one of the leading causes of death, accounting for almost one in six deaths worldwide: amounting to almost 10 million deaths in 2020. As such, its profound impact on individuals, families and society as a whole has catalysed continuous research and innovation in the oncology field. Historically, conventional radiation therapy has been the foundation of cancer treatment methods, however, the requirement for more effective and targeted therapies have become a priority, particularly for cancers that exhibit resistance to standard treatment methods. Approximately one-third of cancers exhibit resistance to conventional radiation therapy, underlining the importance of developing new methods of cancer treatments.

In response, the Head of the Radiation Oncology Department at the Centre Hospitalier Universitaire Vaudois (CHUV), Professor Jean Bourhis and his team have pioneered the development of FLASH radiotherapy; a method of treatment that has shown promise in preclinical animal trials. The emergence of FLASH radiotherapy as a prospective breakthrough is a direct response to the challenges presented by cancer. By offering a novel approach that delivers radiation at extremely high dose rates, the treatment has the potential to improve treatment outcomes whilst minimising side effects by better protecting normal tissue. Due to the difference in the biological response of normal and cancer cells in radiation-induced rates of removal and decay of free radicals, FLASH reduces normal tissue toxicity in its treatments. In addition to its therapeutic benefits, FLASH radiotherapy has the potential to improve the accessibility and affordability of cancer treatment. The cost of cancer treatments, coupled with the additional expenses associated with cancer care

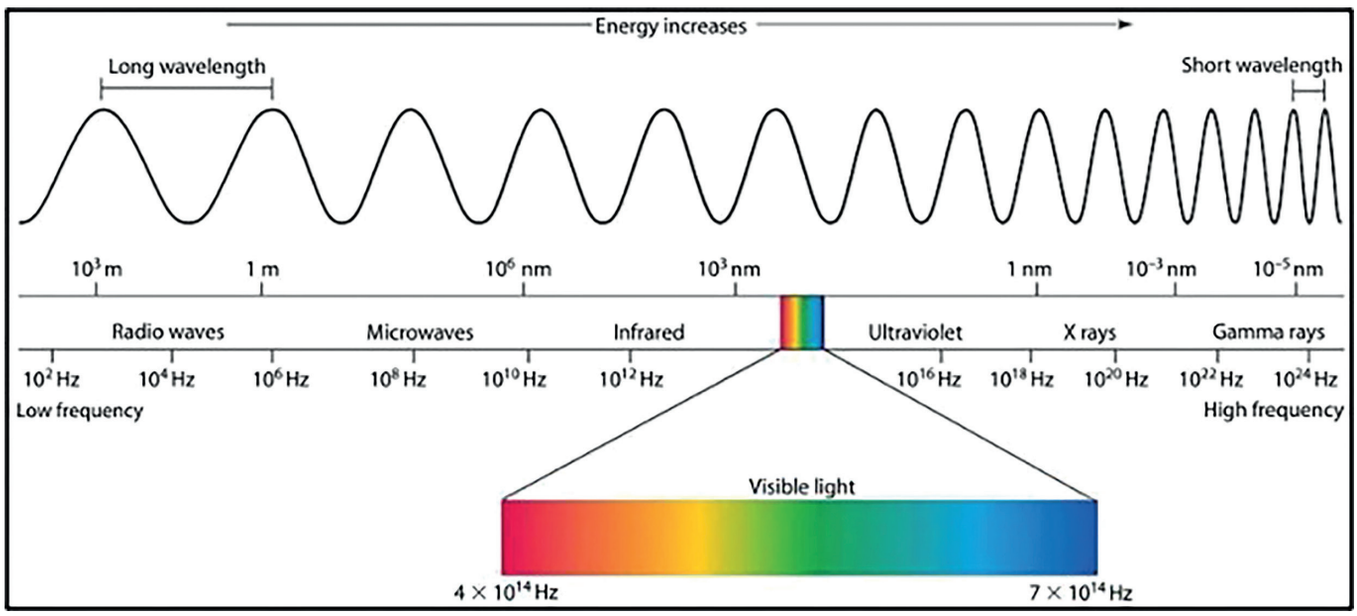

Figure 1: The electromagnetic (EM) spectrum.

and relapses can be financially taxing for all individuals and their families. Hence, the efficiency and effectiveness of FLASH radiotherapy could have a positive impact on reducing costs in several ways. FLASH offers the potential to improve treatment outcomes, allowing for enhanced disease control with fewer side effects. As such, this could lead to reduced treatment times and reduce the need for fewer follow-up procedures, which in turn can lower overall medical expenses. Furthermore, the ultra-high dose rates delivered by FLASH radiotherapy allow for shorter treatment times compared to conventional radiation therapy. This efficiency not only benefits patients by reducing the time commitment required for treatment but also optimizes the utilization of medical facilities and resources. Hence, the more efficient treatment of patients opens the opportunity to save costs for healthcare providers and reduce the strain on healthcare systems. Ultimately, FLASH fulfils a missing aspect of cancer treatment that will not only revolutionise the effectiveness of cancer treatment methods but also contribute to treating more people worldwide.

The desire to overcome limitations in conventional radiation therapy, including resistance and potential harm to surrounding healthy tissues, has led researchers to explore new methods and technologies. By pioneering FLASH, Professor Jean Bourhis, and his team at CHUV, in collaboration with organisations across disciplines and institutions like THERYQ and CERN, have taken significant steps toward addressing these challenges. Organisations like CERN, whilst renowned for their particle physics research, have also recognized the potential of their technologies in medical applications. This recognition, combined with the urgency to find innovative solutions, has facilitated partnerships and knowledge transfer, resulting in the development of unique accelerator technologies for FLASH radiation therapy.

As such, the FLASH technology offers several advantages, including the ability to effectively target deep-rooted tumours. High-energy electrons can be precisely focused and positioned in ways that are challenging to achieve with X-rays. Hence, radiotherapy devices based on CERN's electron accelerator technology can be considerably more compact and cost-effective compared to current proton-based therapy devices. To meet the demands of FLASH radiotherapy, which requires delivering a high dose of very high-energy electrons in less than 100 milliseconds, CERN has helped to design an accelerator based on Compact Linear Collider technology. The collaboration between CERN and partners in different fields highlights the impact of combining CERN's technologies and expertise with strong external partnerships. Mike Lamont, CERN Director for Accelerators and Technology, emphasises this mission of knowledge transfer and the positive outcomes that can be achieved through such collaborations. Hence the multidisciplinary effort not only addresses the challenge of radiation resistance in cancer treatment but also underscores the potential of leveraging advancements in particle physics and accelerator technology for medical applications. The development of FLASH radiotherapy and the collaboration between organizations involved hold great promise in enhancing cancer treatment and exemplify the positive societal impact that can result from the convergence of expertise from diverse fields.

While the progress in FLASH radiotherapy is undoubtedly promising, it is important to acknowledge that further research, validation, and clinical trials are essential to establish and verify its safety, efficacy, and cost-effectiveness. Nonetheless, the collaboration and communication that have fuelled its development highlight the power of collective efforts and the potential for breakthroughs and solutions when diverse fields unite their expertise. As the field of oncology continues to advance, the development and implementation of innovative technologies like FLASH radiotherapy hold great promise. The ongoing multidisciplinary effort to improve cancer treatment is a clear example of the interplay between societal issues and science in striving towards a future where more effective and accessible treatments can help those battling the disease.

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A cumulus cloud can weigh over five hundred thousand kilograms, being heavier than over three blue whales.

Staring into the Cosmic Abyss: the Event Horizon Telescope

Words by Winston Huang (Year 12)

Physics

Published in 1915, Albert Einstein's General Theory of Relativity (GR) explains gravity arises from the curvature of spacetime created by objects with great mass. The motion of particles around an object is affected by this curvature and when the curvature is great enough, the motion of photon, light, will also be affected. German physicist Karl Schwarzschild provided a mathematical solution to Einstein's Field Equation a year later, which described the curvature of spacetime around a non-rotating, spherically symmetric mass.

Ever since then, the existence of a blackhole had been widely debated among physicists until the first image of a super massive blackhole (SMBH), M87 Messier was taken by the Event Horizon Telescope (EHT) in 2019. As shown in Figure 1, the EHT is made up of 8 individual observatories across 6 continents. The imaging technique used, very long baseline interferometry (VLBI) at millimetre wavelength, is able to record radio source with a diameter of 42±3 microarcsecond (μas). Its angular resolution, less than 20 microarcseconds, is one hundred times stronger than the Hubble space telescope. The image of M87 SMBH (Figure 2) and subsequent images taken demonstrate human's strongest evidence for the existence of blackholes and supports the longstanding hypothesis of SMBH powering an active galactic nucleus (AGN).

The event horizon of a blackhole is the boundary which the escape velocity exceeds the speed of light. The radius of the event horizon is in proportion to the size of curvature of spacetime, thus the mass of the blackhole. The theoretical radius of the event horizon can be calculated through using Schwarzschild's Metric and be compared to image taken by EHT, which could validate Einstein's GR and Schwarzschild's theory. The Schwarzschild's radius formula for a nonrotating Schwarzschild black hole is shown below.

The VLBI technique used in EHT involved the linking of 8 radio telescopes around the world to form a virtual earth-sized telescope. This collaboration between 13 institutes enabled magnification high enough to image a tennis ball on the moon

$$r = \frac{2GM}{c^2}$$

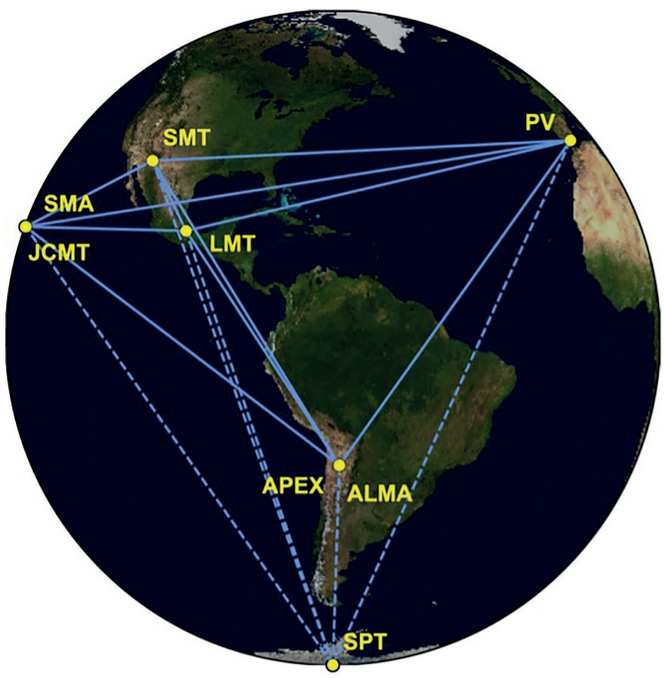

Figure 1: EHT Arrays used for SMBH observations, excluding Greenland Telescope, which joined later in 2018

from Earth as shown in Figure 3. The EHT observed SMBH of M87 and Sgr A on April 5, 6, 10 and 11, 2017 with 7 stations (ALMA, APEX, IRAM 30m, JCMT, LMT, SMA, SMT) across 5 different continents. The data collected from each observatory in the EHT is transported using hard disks to the MIT Haystack Observatory and the Max Planck Institute for Radio Astronomy (MPIfR) for analysis. During the first imaging attempt of the M87 SMBH shadow, four independent imaging teams were formed who attempted to image the data without sharing any

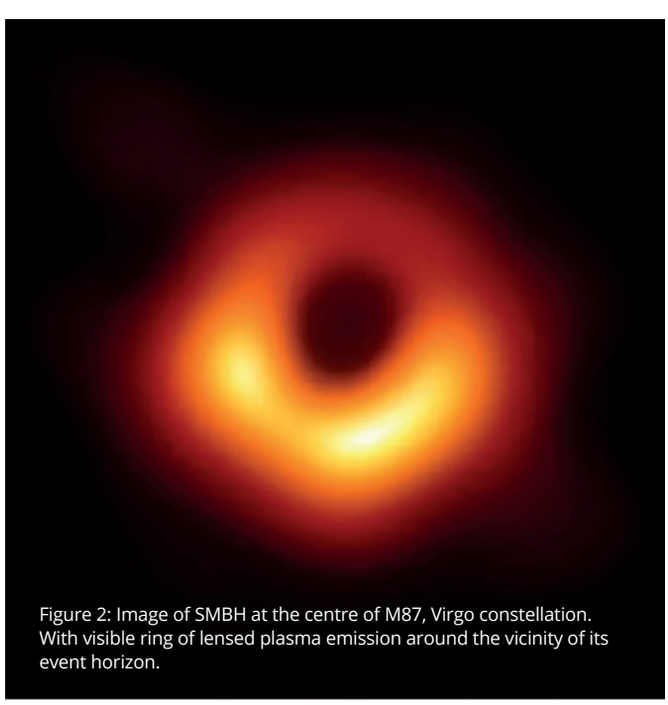

Figure 2: Image of SMBH at the centre of M87, Virgo constellation. With visible ring of lensed plasma emission around the vicinity of its event horizon.

information using the same set of data to avoid any possible biases. The outcome of this collaboration was the production of four very similar shadow images through using 4 days of data, thus maximizing the validity of the final image.

Scientists specialising in the theoretical and observational field also collaborated in proving the nature of the M87 SMHB. As shown in the resultant image, the distribution of accretion flow around the black hole is asymmetric. This shows that the black hole is rotating which the direction of emission towards earth is boosted by the Doppler effect, resulting in greater intensity of brightness. Through the image, the spin axis can be determined as pointing away from Earth and both evidences align with the theoretical model described by the Kerr metric and spacetime concept of GR. This collaboration between theoretical and observational result confirms both models and further improves our understanding of gravity in its most extreme limit.

For the later imaging of the Sgr A SMBH at the centre of the Milky way galaxy, more advanced telescopes joined the EHT collaboration, notably the Africa Millimetre Telescope (AMT, Figure 3) and Canary Islands telescope (CNI). This resulted in an increased coverage in the East-West direction which allowed a longer imaging time of 7 hours for the high-fidelity movie reconstructions of Sgr A. The collaboration of more advanced telescopes in a wider range of geographical areas provides more possibilities for the imaging of further deep sky objects.

As shown by the Schwarzschild's radius equation, the mass of M87 SMBH can be determined through measuring the radius of its event horizon. The images provided by EHT made this possible and an around 38 billion kilometres diameter was obtained. The theoretical mass of the black hole was calculated and calibrated to be solar mass and is supported by the stellar dynamic measurements.

A number of stars known as the "S stars" closely orbit around the SMBH of Sgr A and the closest star, S4714, approaches the event horizon at a distance of 12.6 AU, roughly the distance from Saturn to the Sun (Figure 4). The speed of this star exceeds 8% the speed of light due to the immense gravitational pull and it's the fastest star observed in the universe. The Very Large Telescope (VLT) in Chile had been observing the behaviours of those stars for 20 years and through observing the impact of the black hole's gravitational field, a theoretical mass was obtained and was very close to the mass calculated using EHT imaging. The application of EHT imaging for Sgr A SMBH was successful in confirming the mass predicted by the theory of stellar dynamic measurements.

The EHT can also be applied in the Geodesy field, an area of science studying Earth's gravity, rotation and shape. The application of Geodetic VLBI started in the 1960s and the technologies had been refined to produce more accurate results. This process involves multiple radio telescopes from various locations, making measurement on a Quasar which appear at fixed point in space. Through measuring the distance of each telescope from a fixed object at the same moment, VLBI enables geodesists to know the exact location of each array and calculate how fast the earth is rotating. The collaboration of EHT and the joining of more advanced telescopes from a wider range of areas, allowed the production of extremely accurate measurements. The application of

Figure 3: Africa Millimetre Telescope (AMT), as a new addition to the EHT collaboration in 2020.

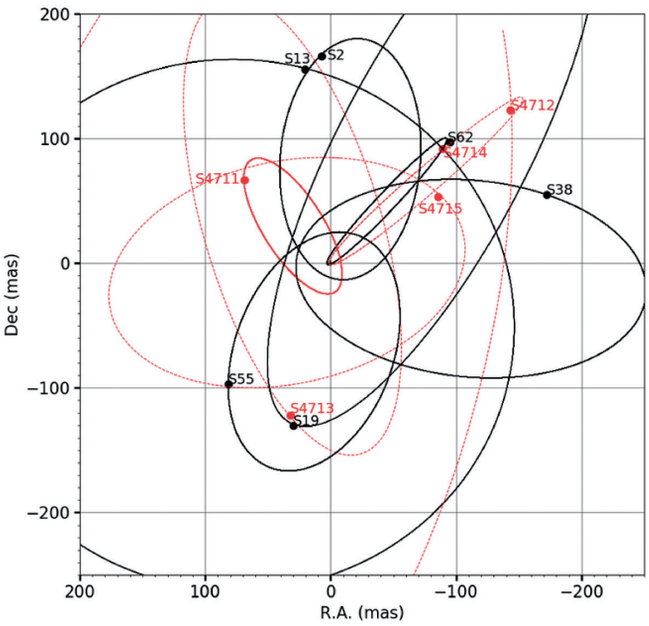

Figure 4: Motion of stars around SMBH Sgr A at the center of Milky way. Observed over 20 years by VLT in Chile

EHT's precise VLBI enabled scientists to maintain an accurate measurement of Universal Time (UT1).

As the EHT collaborators have arrays from multiple continents, the motion of tectonic plates could also be studied. EHT's geodetic VLBI measured that North America and Europe plates are separating at a rate of 17 millimetres per year as well as the position shift of San Andreas fault in California, at a rate of 5 centimetres per year.

In summary, the eight arrays of the EHT allowed scientists to deepen the understanding of particle behaviours around SMBH and demonstrated further support for Einstein's GR. The first image of M87 SMBH provided the strongest proof for the existence of black hole in the universe as well as its nature of a rotating BH. The application of EHT data is valuable for other purposes such as determining the movement of tectonic plates and testing theoretical theory calculations against observational data. The joining of more telescopes into the EHT collaboration allows longer exposure time, thus the production of higher quality SMBH image.

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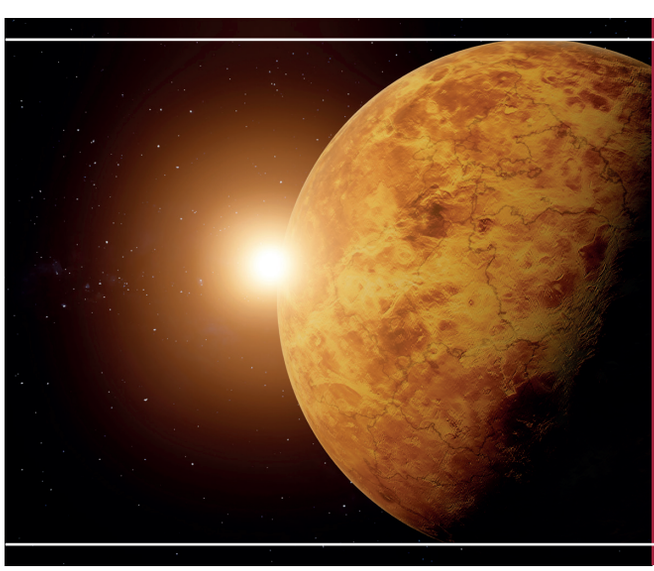


It takes Venus about 243 Earth days to complete one rotation, while it only takes 225 Earth days to orbit the Sun.

Science Competition Award Winners 2023

Australian Science Olympiads High Distinction

Owen Chen (Year 10)

International Chemistry Quiz High Distinction (Year 11)

Lachlan McKay

Son Banh

Fred Vartuli

Big Science Competition High Distinction

Harry Paholski (Year 8)

Harry Grandioso (Year 8)

Owen Chen (Year 10)

Oliver Fenton (Year 10)

Luke Economos (Year 10)

National Titration Competition (Year 11)

Eli Anders (National Finalist)

Peter Moore (National Finalist)

Arjun Dosanjh (National Finalist)

Oliphant Awards

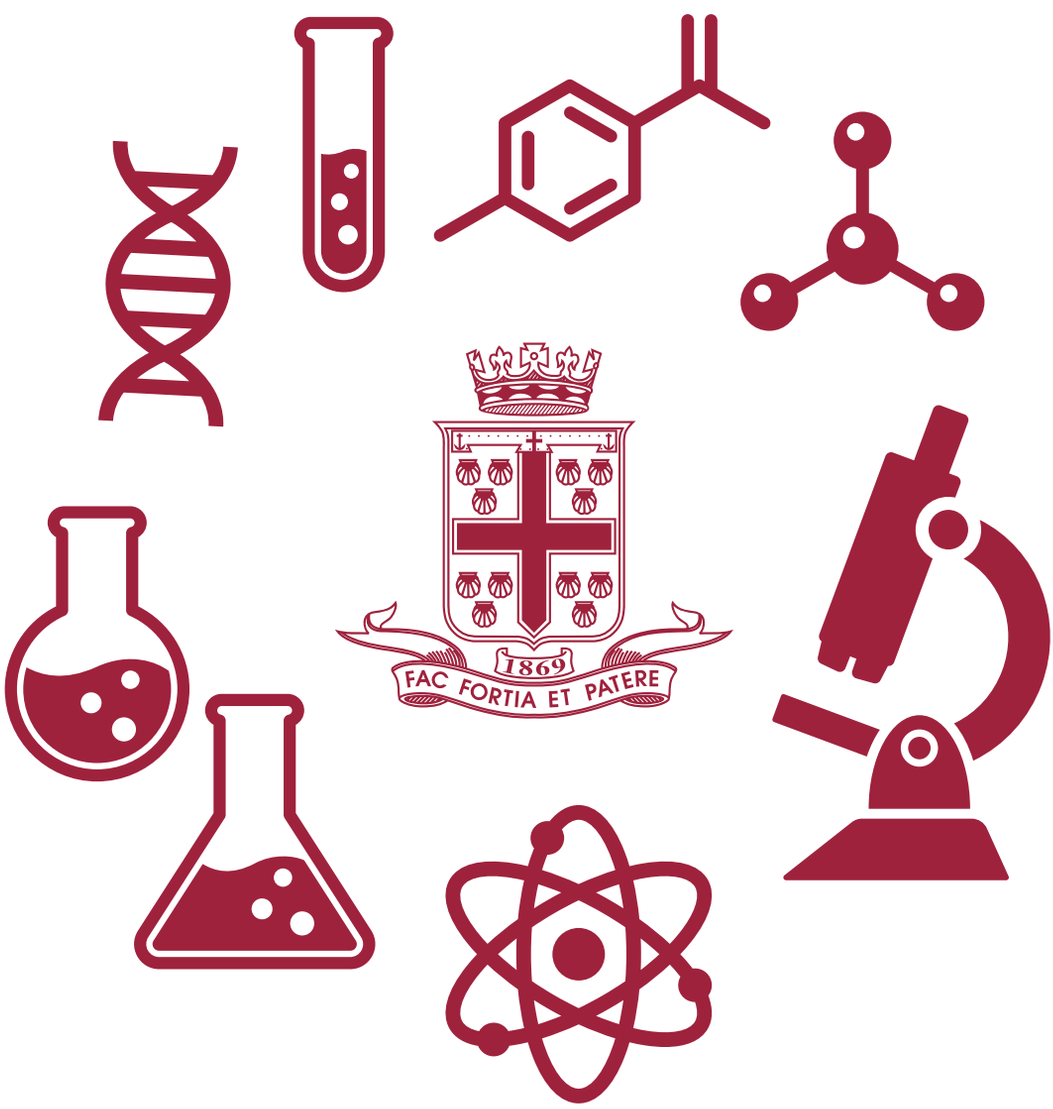
Regan Nelson (Year 12) - Multimedia Year 11-12

Science Investigation Awards

Lachlan Logan (Year 7)

Crystal Growing Competition (Year 8)

Jackson Finnis (National Finalist)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