Edition 77

PRINCE
ALFRED
COLLEGE

2021

PAC SCIENCE JOURNAL

A BRAVE NEW WORLD

The future may not always be clear. But fearless thinking can bring it into focus.

Over the past couple of years, we've become accustomed to saying that we live in uncertain times, but the truth is – we always have.

The future has never been certain. Tomorrow has never been clear. And we've always needed fearless thinking and brave research.

At Flinders, our science programs and degrees are helping uncover the secrets of the past, the present and the future. Our researchers work with industry to create ground-breaking solutions to global problems, and the cutting-edge skills of our graduates are helping drive the new knowledge economy around the world.

The future may not always be clear, but Flinders' brave research and fearless thinking strive to bring it in to focus. We don't simply survive in testing times, we thrive in them.

Be fearless.

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Flinders UNIVERSITY

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A word from the Editor

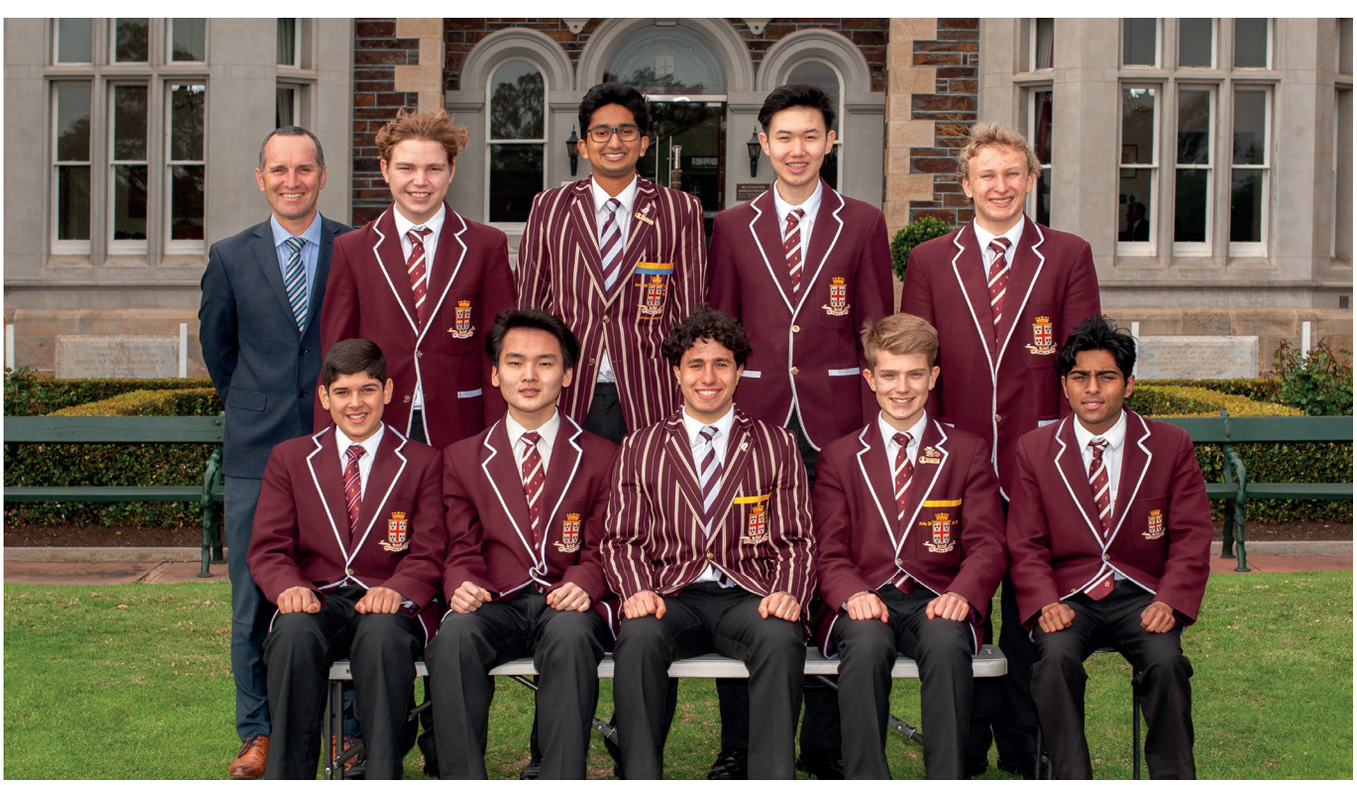
Emerging from the momentous year of 2020 and Coronavirus playing a major headline within today's society, the 2021 Science Journal has provided a profound insight into the future of science. With this year's theme "A Brave New World" referring to Aldous Huxley's famous fiction dystopian novel, the journal aimed to encapsulate the next biggest question – how do we move on from the Coronavirus? From the challenges faced with the global pandemic, scientists have considered novel approaches to well-established problems such as health, climate change and even space travel. News from across the world indicate that COVID-19 has made humans transition into a new world, where the interplay between science and society is more important now than ever. The new world is very much exemplified through the scientific advancements over the past few years, such as new vaccines and cancer treating drugs, to theoretical Dyson spheres, to food authentication techniques. The new world causes society to consider the role of governments in the COVID response and their energy plans. It even causes us to think on why we do mathematics and its importance. Overall, the daunting and unknown future shall be filled with many challenges, challenges that as a society we can face using science and what it has to offer.

The purpose of the science journal is more than to provide students the opportunity to share and publish their work in science. It is used as a reminder of how science stems way beyond from what is taught in the classroom, where the possibilities and discoveries are endless. Science is a perpetual field which stimulates individuals to ask questions of why and how, questions which have pivotal relevance in the modern world. Therefore, it has been through the science journal that individuals can explore the 'how and why', important questions that define the human race.

I would personally like to thank Mr Hopkins for all his work in contributing towards the science journal and its impact on Prince Alfred College. The tireless effort and dedication that he has towards the journal is the primary reason for its success, and I thank him from the bottom of my heart. I would also like to personally thank all the science staff and lab technicians at the college. It is through their teachings and wisdom that students become curious and explore scientific endeavours outside of the curriculum, so I say thank you very much for your efforts. I would like to specifically thank Eric Luksch, who designed the cover of the journal and promotion posters. The cover is designed to encapsulate the journal's theme, and Eric has successfully achieved this goal, so I say thank you very much. Would also like to thank members of the science journal committee, for their work in editing articles and helping with the theme for this year. Finally, I would like to thank all students at the college for their contribution and support of the journal. The journal is a celebration of student work, where their genuine interest and support allowed this to occur, so I say thank you.

I am very honoured to be the Chief Editor for the science journal for 2021. I am looking forward for the rich tradition of scientific writing continuing in the years to come and cannot wait to see how Princes Men will make their mark on the scientific community and the world in the future.

Dinan Perera
Chief Editor, 2021



Science Journal Committee 2021
Back Row: Mr Peter Hopkins, Eric Luksch, Dinan Perera (Chief Editor), Jiarui Zhang, Regan Nelson **Front Row:** Saverio Blefari, Hyunseok Kang, Peter Moutos, Max Thomas, Rahul Ravindran **Absent:** Winston Huang, Henry Nind

Front cover artwork: Eric Luksch (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 atRockingham General Hospital, in W. Australia.

Richard Nicholls, 1963

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

Adrian Wilson, 1964

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

John Loxton, 1965

Dux of the School, John completed a B.Sc. at Melbourne University and was awarded the Wyselaskie Scholarship, followed by a M.Sc. and PhD from Cambridge University. In 1988 he was appointed Professor of Mathematics at Macquarie University and in 1995 was inducted as Deputy Vice Chancellor (Academic). John left Macquarie University in 2007 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 currently working as a radiologist in Adelaide and a 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 enrolled in Medicine, University of 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

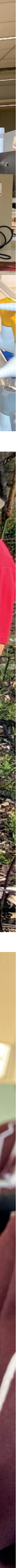
Denny studied the IB Diploma in 2018-19 and after contributing to the Journal Committee for several years was Chief Editor in 2018. He is currently studying at New York University – Abu Dhabi.

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.



Contents

New Opportunities for Australian Food and Agriculture

Words by Associate Professor Matthew Tucker

Guest article

The past two years have been remarkably challenging on a domestic, national and international level. The Covid19 pandemic has affected our lives in ways that many of us never thought possible. Changes include a rapid switch to online learning, difficulties in crossing state borders, a long "pause" on international travel, and a reminder of how lucky we are to live in Australia. For me, this pandemic has reaffirmed my belief that it is vitally important to develop and embrace new technologies. An example of this is the mRNA vaccine technology that was once considered controversial, but is now the preferred option for defending against Covid19 symptoms and transmission. It is hard to predict exactly what is around the corner, but we need to be prepared for the next disruptive event or technology that might change the world.

The optimistic view of disruptive events is that they bring opportunities, particularly for young people. When I was growing up during the 80's and 90's, one of the key disruptive events was the development of genetically modified plants. Prior to this time, "genetic engineering" had been used for years in yeast and bacteria to optimise fermentation processes (e.g. beer and cheese production) or the synthesis of human therapeutics (e.g. synthetic insulin). However, GM technology appeared to offer so much more in plants, including the possibility to alleviate issues in human nutrition through engineering vitamin-enriched food crops, or to create biofuel-ready plants to replace fossil fuels. This technology was exciting enough to turn me away from the idea of studying law, and instead complete a Bachelor of Biotechnology with a dream of becoming a genetic engineer who might deliver tastier tomatoes, black roses, and golf course fairways that needed less water.

It is interesting to track the progress of GM plants since then; first the excitement of discovery, then the appearance of GM plant products such as the shelf-stable FlavrSavr tomato, next the ethical concerns about big business owning the technology, and finally the inflation of public concern regarding the safe use of GM technology. Fast forward 30 years, and GM plants are still a hot topic! GM crops such as cotton and canola have been grown in Australia for over 20 years, and for the first time can be freely grown in South Australia during the 2020/21 season. Public opinion surveys suggest consumers are more comfortable with GM plants than ever before. The same surveys indicate that Australians are happier to eat GM foods than foods grown with pesticides, which is interesting given the high prevalence of pesticide use in comparison to the relatively low presence of GM products on Australian supermarket shelves! It is also clear that I am not the "genetic engineer" of my dreams. Rather, my career has evolved to become an academic researcher who uses conventional genetics as well as GM plants to investigate how plants grow and produce seed.

Figure 1: GM canola has been planted commercially in South Australia for the first time in 2020/21

Changes in societal views have been achieved through better science communication, realisation that GM plants will not take over Australian agriculture, and greater understanding of DNA technology. We now have genome sequences available for many plants such as potato, tomato, barley and wheat. This provides us with the sequence of every gene and allows researchers to find genetic variants that might contribute to improvements in crop yield, disease tolerance, or even tell us what type of grain was consumed by miners 800 BC during the Iron age.

Figure 2: Seeds and grain are worth over $12B to the Australian economy

I am often asked whether agriculture is sustainable in Australia , whether there is a future for GM food crops, and what disruptive technology will come next. This should be considered in light of current agricultural production levels, as well as future government and industry targets. Agriculture in Australia is currently a $60B industry. Approximately 70% of our agricultural products such as wheat, barley, grapes and pulses are exported, with the majority destined for South East Asia. Despite current trade issues with China, the Asian demand for these products is predicted to almost double between now and 2050, suggesting there are amazing opportunities for producers of high-value,

Figure 3: The author standing in front of massive piles of imported grain in Guangzhou, China

high-quality agricultural and food products. In parallel, the National Farmers Federation recently released plans to turn the Australian agriculture industry into a $100B industry by 2030. In South Australia, this is mirrored by a GrowthState agenda to transform our agriculture, food and wine sector into a $23B industry by 2030, up from approximately $16B at present. These are exciting numbers and almost certainly will be supported by the formation of new jobs in the cities and regions, but the question is how can we achieve these targets in the face of a changing climate, increased severe weather events, reduced water availability and an aging workforce? One answer is to make sure we build on our strengths in research and development, unite historically disparate disciplines, and prepare an educated workforce that can capitalise on new disruptive technologies. The agricultural growth targets cannot be achieved simply by producing more of the same crops. Rather, it is necessary to become more efficient at extracting value from current production systems to deliver new and enhanced products. It may also mean that we need to develop new crops to complement our historical strengths in winter crops such as wheat and barley. These approaches will need to be sustainable and targeted to future market opportunities.

So how will genetic technologies contribute to this? Conventional plant breeding will remain a key conduit, but it is certain that GM plants will play a role. Recent examples of global progress in this area include GM wheat plants from Argentina that are resistant to drought, yielding 20% more than conventional wheat cultivars under water-limited conditions. In Brazil, scientists have developed GM eucalyptus plantations that produce 20% more wood than conventional plantations and are ready for harvest in 5 years instead of seven. In Australia and Asia, GM crops such as Golden Rice, Super Banana and Golden Potato are being developed or cultivated as part of efforts to combat blindness caused by vitamin A deficiency. In the UK, Indigo tomatoes are being promoted as an antioxidant-rich fresh product that can reduce the activity of free-oxygen radicals that cause cancer.

Even if GM isn't the only solution, the next generation of genetic technologies are already on our doorstep. Gene editing, otherwise known as CRISPR/Cas9, has evolved so quickly that is has now become a routine, precise technique to target specific changes in the DNA. Particularly effective in plants, CRISPR-induced changes cannot be distinguished from natural mutations that appear through exposure of DNA to sunlight, X-rays or even chemicals such as bushfire smoke. This technique offers immense promise and has been approved by Australian regulatory bodies as a non-GM technology. The next generation of genetic engineers will almost certainly use gene editing in partnership with computer scientists, physicists, nutritionists, agronomists and breeders, to deliver new crops and products that are resilient, valuable and sustainable. If I'd been armed with this toolkit 30 years ago, I think we'd probably be growing plants on the moon by now! Although it sounds remarkably far-fetched, such an opportunity might be closer than we think.

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Ode to Dr Murphy

Words by Dinan Perera

Thought starters

"I want to be known as a good doctor, not a good autistic doctor" – Dr Shaun Murphy

Introduction

Albert Einstein once said that "in the middle of difficulty lies opportunity", where over recent history some of the greatest minds and innovators have had to overcome immense hardships to obtain their accomplishments. However, no other challenge would be greater than those who experience disabilities. Approximately 190 million people worldwide suffer from some form of disability, and approximately 450 million worldwide suffer from a mental or neurological condition that impairs their ability to cognitively function to what they are capable of. Physical disabilities such as amputations or paraplegia, chronic disorders such as schizophrenia or bipolar disorder and those with autism spectrum disorder, all present great challenges including social stereotypes which often differentiate these people from those who are perceived as "normal". However, the concept of normality has never been more obscure within our current society, where many so-called sufferers have not seen these conditions as setbacks, but as Einstein stated, as opportunities. By pushing the boundaries of what is conventional, there are countless discoveries, breakthroughs and lives saved which are attributed to individuals with these conditions. Therefore, it is important to acknowledge, recognise and learn how those with the greatest challenges can achieve the greatest outcome for the betterment of mankind, and like Dr Murphy, should be seen as just like us.

The reality behind physical and mental disability

What many people do not understand, is that physical and mental disability has a long-standing and permanent effect on individuals. Despite the short-term symptoms and treatment that may be able to alleviate certain pains in the body, the effect of dealing with such disabilities and adjusting one's life is permanent. In 2013, the Ontario University outlined the "five barriers to accessibility" for people with disabilities, describing them as Attitudinal, Systemic, Physical, Informational and Technology. All these barriers encompass difficulties that individuals with disabilities deal with daily, both within and beyond their control. Therefore, whilst these individuals must deal with physical or mental handicaps from their personalised condition, they are further faced with limitations and hardships which are enacted by society.

However, the greatest debilitating issue of disabilities is the associated mental health issues that arise due to these five barriers. According to Australia's Health report in 2020, 42% of people with severe or profound core limitations reported anxiety-related problems, 36% reported severe mood disorders and 17% experience high levels of psychological distress. Such conditions can adversely affect the lifestyle of these individuals, as 57% report insufficient physical activity, 72% report levels of obesity and 14% report risk of high-level alcohol consumption. Therefore, people with disabilities often require the greatest amount of holistic care.

Disabled Scientists which made the world a better place

However, it has been through the contribution and work of disabled scientists that we can enjoy the society we live in today. A famous example of an individual who persevered through their disability is Stephen Hawking. Whilst he was 21 years old, he developed a severe nerve and muscle disease called "amyotrophic lateral sclerosis", which made him bound to a wheelchair when he was 27 years old. Hawking's condition was very serious, such that he required a voice synthesiser to assist his speaking. However, his condition did not hold him back in his discoveries in cosmology and black holes that were important for society. Hawking would later quote that he tried not to remain disabled in his mental psyche, stating that *"my advice to other disabled people would be to concentrate on things your disability doesn't prevent you from doing well and don't regret the things it interferes with. Don't be disabled in spirit, as well as physically".*

Wanda Diaz Merced is another example of an individual who was not held back by their disability and instead used it as inspiration to achieve wonders. As a young adult, Wanda developed problems with vision due to altercations with diabetes, ultimately losing her eyesight. However, losing her ability to see did not affect Wanda's passion for exploring the universe and looking at the stars. Working with researchers in Scotland and the United States, Wanda developed a technique to study the space phenomena of gamma-ray bursts through sonification, which converts data from space into sound. Such technology not only enables her to interpret information but also allows scientists to deal with different cosmological phenomena such as eclipses, detecting shifts in variable stars and boost the sensitivity to subtle events.

Naomi Ondrasek is another example of a scientist who was able to overcome their disability and disease which would provide significant hardships to them. She's a biologist at the University of California and is plagued by an autoimmune disease. Naomi suffers from a variation of inflammatory bowel disease (IBD), with symptoms ranging from frequent diarrhea to intense and sharp stomach pain. However, she perseveres through the pain and continues to study the role of hormones in the brain. She continues her study on hormones such as nonapeptides, which circulate in the body and maintain metabolic processes and oxytocin, which helps control the birthing process and subsequent milk production in mammals. However, Naomi suggests that such secretion of hormones illicit certain social behaviours, with oxytocin causing organisms to feel love and trust for another organism. Therefore, such behaviours can have a similar impact on humans and the way

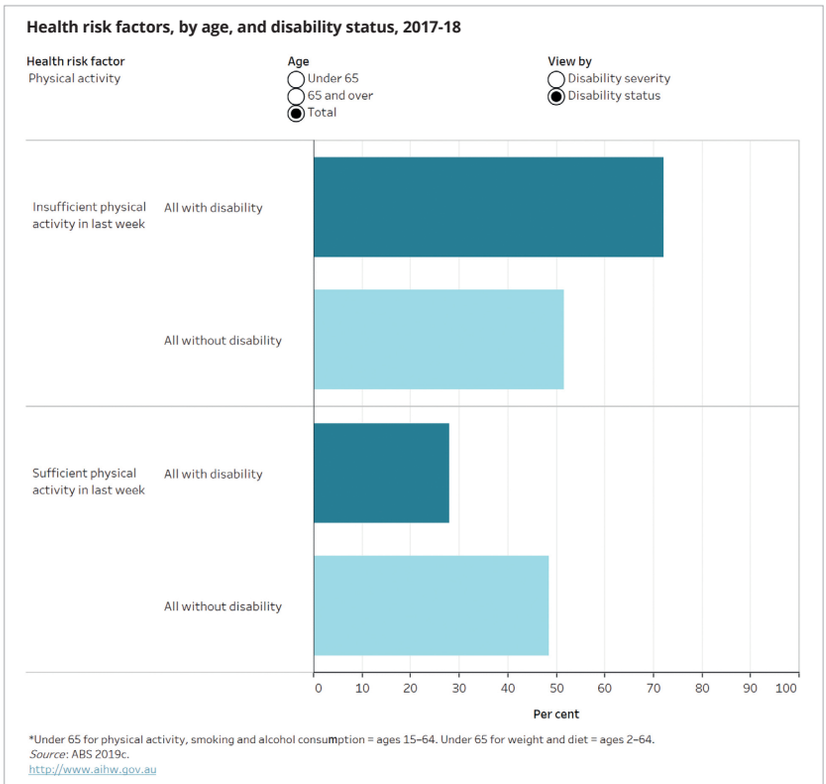

Figure 1: A comparison of the level of physical activity for those with and without disabilities.

Figure 2: Dr Shaun Murphy

we process human emotions. Ultimately, Naomi still faces IBD, as she claims that "*though I have all these health issues, I was able to persist my career"* and she has been able to make significant contributions to society.

One individual who personally exemplifies the type of strength and character required to overcome societal challenges in the pursuit of science and health is Dr Shaun Murphy. The fictional protagonist in the popular show "The Good Doctor", Shaun is an individual who was required to overcome prejudice and judgement whilst dealing with both his patients and co-workers at St Bonaventure Hospital. Shaun was diagnosed with autism at a young age, which persisted whilst he emerged into adulthood. Due to his difficult upbringing with an abusive father and being reliant on his older brother (who died whilst they were both young), Shaun was not provided with the sufficient care that he so desperately needed. As a result, this has led to problems in his ability to understand social cues, recognise the various human emotions and ability to communicate – all qualities expected in a surgeon. However, through the help of the president, Dr Glassman, Shaun was still allowed to be a surgical resident – one of the best residents there was.

Shaun's condition, whilst initially conceived as a set-back, was not considered a gift and provided an alternative perspective of health care that was much needed today. Whilst Shaun was also gifted with Savant Syndrome, contributing to his multi-faceted understanding of anatomy and human conditions on an unprecedented scale, it was his personal connections with doctors and patients that had an everlasting impact on those around him. Shaun's inability to communicate was compensated by his persistence in maintaining health and providing the best outcomes for his patients. Shaun's presence in the hospital meant that surrounding characters such as Dr Neil Melendez, Dr Lim Chang, Dr Claire Brown, Dr Alex Park, and Dr Morgan Reznick, were able to become better individuals and better at their profession. Despite initial prejudice and resistance held by the entire community, Shaun was motived to become the best resident possible and prove his self-worth. It was because of Shaun that babies could be born, lives could be saved, families could be restored and patients could be treated when others thought otherwise. Ultimately, Shaun had an everlasting on the community and patients of St Bonaventure Hospital, where his fictional journey continues today and proves that those with disabilities are capable of extraordinary achievements.

In conclusion, the millions of people across the world who deal with some form of disability must pay the biggest price. However, this does not seclude them from making a large contribution to the science community and ultimately making a difference. We should commemorate the work of individuals like Dr Murphy, who do not only change the world through the work that they do but also become an inspiration to others with disabilities. Such lessons are also applicable to those without disabilities, as it suggests that we are only limited and held back by our capacity to think that we are limited. Therefore, all individuals must strive for greatness and pursue their passion, no matter what obstacles life throws at you.

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Why is Mathematics?

Words by Kyan Jenkins

Thought starters

I don't know if God is real. If mankind built the closest thing possible to an all-knowing omnipotent entity that was possible, it would probably be the internet. If our man-made god were to have a child, that child would be Google. This article isn't about God or Google. But if you search "when was mathematics first used", in Google, you will receive an immediate result that suggests an answer of the 6th century BC, with a photo of Gottfried Leibniz. This demonstrates the shortcomings of Google in two ways. Firstly, the 6th century BC was actually not that long ago, and so it seems intuitively false that answer is true. Secondly, Gottfried Leibniz, a key contributor to our understanding of calculus, was born nearly 20 centuries after the date of this incorrect answer. Nonetheless, my second Google search was more satisfactory. Considering mathematics, by its crudest possible definition, is the field that concerns the abstraction of quantity, space and change, it is more appropriate to ask when counting was first used. The answer can be found easily enough through a Google search and is left as an exercise to the reader.

One of the simplest equations that could possibly exist summarises beautifully the suggestion that two quantities, the sum of *a* and *b* can be written simply as a single quantity *c*. That is formally:

$$a + b = c$$

I could not find an answer as to how long this formal understanding has existed, although I am almost certain it predates the existence of the iPod (I cannot be sure, as the iPod was made three years before I was born).

Many years later, around 1900 BC, the Babylonians discovered an interesting relationship which they then decided to inscribe onto some clay. Pythagoras of Samos and his worshippers, a bit over a thousand years later, decided that this deserved further consideration. And so was born the thinking behind Pythagoras' theorem, which suggests that where *a, b* and *c* can be imagined as side lengths of a right-angled triangle:

$$a^2 + b^2 = c^2$$

And then everyone relaxed for a little bit. Then Pierre de Fermat suggested in 1637 that there were no solutions to the general equation:

$$a^n + b^n = c^n \quad \text{where} \quad n > 2$$

That is, Fermat suggested that the only solution to this equation were for those previous cases mentioned above (when *n* takes the values 1 or 2). Famously, this is titled 'Fermat's Last Theorem'. Fermat wrote, in the margins of a book which floated this conjecture:

"*I have a truly marvellous demonstration of this proposition which this margin is too narrow to contain*".

And then, soon after that, he died. In reality, Fermat's Last Theorem is a misnomer, because he never proved it (or at least, extensive search was never able to find a copy of his proof). It was Fermat's Last Conjecture.

Fermat's inability to simply write the proof on the nearest piece of paper and be done with it was to the dismay of thousands of mathematicians who dedicated their entire careers trying to prove Fermat's conjecture. That is until 1993 when Andrew Wiles solved it. Notably, it was a 108-page proof, which is quite a lot of margins. Fermat's Last Theorem has no explicit practical application. It was mathematics for the sake of mathematics.

Fermat's Last Theorem is an interesting story of perseverance, belief, and human triumph and is one to inspire any young mathematician to try and understand the impossible. Yet the story of Fermat's Last Theorem answers a more important question: why is it that we as a society value pure mathematics?

As an aside, if you think that pure mathematics is useless, that is a completely understandable belief to hold. Our government, through their unprecedented cutting of university funding towards research, suggest exactly that. They are more than happy to punish students of the arts in order to incentivise more schoolchildren towards STEM careers, but what they are really pushing students into are *industry* careers, to which there is an important distinction. Pure mathematics does not solve the government's fiscal issues. Regardless, if you aren't convinced that pure mathematics is of much benefit, then treat my thesis as the solution to whether or not pure mathematics is useful, and my writing as justification as to why.

The Langlands program is a compilation of conjectures which aims to come to a conclusion on the connection between two areas of mathematics: geometry (the study of shapes and space) and number theory (which demands no elaboration). The actual nuances of the Langlands program are far too complex for me to even consider explaining (because it would require me to actually understand it), so my explanation will extend to simply the following, as no more is relevant to my point anyway. The program seeks to specifically connect Galois groups to automorphic forms.

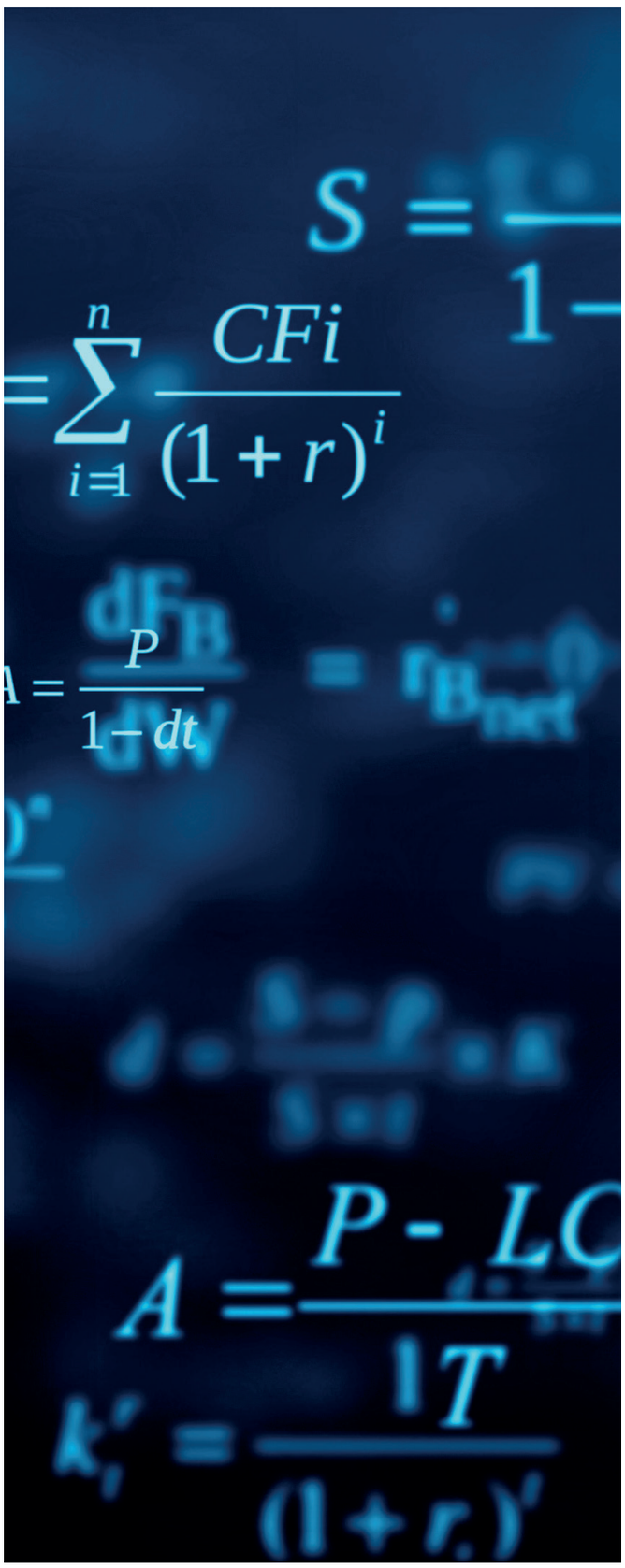
Simply put, a Galois group connects two mathematical objects, a field and a group, via the fundamental theorem of Galois theory. A group is a set of elements with a respective binary operation which is associative, such that two elements of that group acted upon are equal to another element contained within that group. A group also has an identity element and inverse elements. An example of a group is the set of integers under addition, as the sum of two integers is both associative and equals another integer, zero is the identity element, and the inverse of an element is the opposite of the integer. A field follows the same principle, however has two binary operators acting on the elements of the field *F*, whereby one operator

is commutative and the second operator is distributive over the first. An example of a field is the rational numbers under the commutative group addition, and multiplication, which is distributive. With this in mind, Galois theory says we can reduce many problems related to field theory into problems of group theory, which are generally easier to work with. A Galois group in relation to polynomials, is all the possible permutations, sometimes called symmetries of an *n*th degree polynomial's *n* solutions. The reason this is useful then is because it allows a greater understanding of what polynomials are and aren't solvable.

The other part of what the Langlands program connects, automorphic forms, is suggested by Langlands to follow the same principle of Galois theory and Galois. However, while Galois worked with polynomials, automorphic forms come from a completely different field of mathematics, namely harmonic analysis, which concerns functions which can be constructed as the sum of many sine waves. Fundamentally, the Langlands program is analogous to string theory, in that both try to unify two fundamentally different fields of their respective subjects in order to try and provide an explanation. In fact, the Langlands program has distinct applications if its conjectures are proven, not only in other mathematical areas which have clear tangible benefits such as cryptography, but also to fields such as physics. The Langlands program aims to formulate a connection of otherwise unrelated mathematical fields, and in turn has deeply important implications for theories such as string theory, which also attempts to unify concepts within the science of physics.

Incidentally, Wiles' proof of Fermat's Last Theorem plays a key role in our current understanding of a subset of the Langlands program, and has clued mathematicians as to how to approach the current issue faced within this new conjecture. Ultimately the point here is that, through a study of mathematics for no clear reason other than to solve an unsolved problem, such wide range of understanding can be gained that it can lend itself to benefit in so many fields simply via the expansion of knowledge surrounding unknown systems.

But let's move on from what was an inspirational but otherwise brain-melting view towards pure mathematics. Perhaps it should be considered that pure mathematics really is quite distinct from applied mathematics. The field of mathematics, in this sense can be considered as separate from the tools which are used in mathematics, and the two broadest branches of maths can be considered as two separate fields. Much like the artist and the author use the pencil for wildly different purposes, the study of pure mathematics should simply be able to be for its own sake. Maybe we should just be able to accept that mathematics is beautiful, and seemingly meaningless theorems are, even if not fun to work on, enjoyable to look at and interesting to read about. Its existence shouldn't demand justification much like plenty of other scientific work does not, and much like art does not.



The Fine Art of Making Mistakes

Words by Mr Peter Hopkins – Academic Leader Science

Thought starters

"The only real mistake is the one from which we learn nothing" – Henry Ford

I attended a careers night presentation few years back where a university professor detailed to the students what a career in scientific research looked like. It prompted me to ask him what sort of attributes he looks for in his students. He did not hesitate by saying that in his opinion, a willingness to make mistakes and just as importantly, an ability to carefully consider the results they had just generated, interpret them and think logically about what to do next were critical. He continued to say he had seen many students who had navigated their undergraduate courses receiving numerous high distinctions and university awards and medals yet could not function in any way shape or form in a research laboratory during their post-graduate studies. He said they lacked the willingness to make mistakes and to think laterally for themselves.

This resonated with me in that in a past life prior to embarking on a teaching career, I worked as a research scientist, focussing mainly on gene therapy techniques in relation to the genetic disease Cystic Fibrosis. Reflecting on these years, more often than not when conducting an experiment, the results obtained were not what were expected. In the language of a school practical report *"the hypothesis was not supported."* This demanded a significant level of lateral thinking to interpret what these results meant and importantly, a considered decision as to what direction we should move forward with our research.

With a focus – sometimes an infatuation - on gaining the best result possible at the end of Year 12 I have noticed an increasing trend in student's lack of willingness to make mistakes with anything they do in Science. Some arrive at a point where they refuse to attempt difficult, more applied questions. They do not know where to start for fear of making a mistake.

When considering the school context, practical work is usually completed in order to reinforce concepts being taught. This is an important aspect of practical work, however, for a student who has been listening and participating in class, it can at times just repeat what has just been taught. As a result, I would suggest that for a significant amount of time, students know what they will see from their results well before they embark on the practical exercise. How does this approach instil an ability to think laterally about abnormal results when for the most part our students know what results they should obtain even before they have them in front of them? How does this approach instil an ability to think laterally about abnormal results and willingness to make mistakes if our students rarely make them – or are provided with opportunities to do so?

The willingness to make mistakes and then think laterally about them are attributes that I feel need fostering in all of our students. The acquisition of deep knowledge is undoubtedly essential to developing these attributes in a student. However, whilst we quite rightly focus on imparting knowledge to our students, are we giving our boys enough opportunities currently to make mistakes (and feel comfortable in doing so), and then develop their ability to use the knowledge we impart upon them to think in a more lateral way when errors are made?

At Prince Alfred, we currently offer both South Australian Certificate of Education (SACE) and International Baccalaureate Diploma (IBDP) pathways for our senior boys. Currently, I do not see a discernible difference in boys from either cohort being able to think in this way. Our IBDP boys complete an investigation called their Internal Assessment (IA) where they need to design and conduct a novel experiment. Their report associated with this investigation is worth 20% of their final grade. Similarly, the SACE students conduct 'Deconstruction and Design' experiments. These tasks demand that they design and carry out a practical investigation where their methodology has to be centred on an experiment of an 'unknown outcome'. Each year I see boys struggle with both of these tasks. I recall one of my academically strongest SACE students from a few years ago. When he conducted his Deconstruction and Design experiment, he obtained a very strange set of results which he was at pains to interpret. The look of fear on his face when grappling with this issue was clear. His attitude was *"I must have made a mistake. What have I done wrong?"* The truth was neither had occurred. He conducted a well-designed, controlled experiment. However, for the first time in his schooling he had obtained unexpected results - the sort of outcome a post graduate student or research scientist achieves most of the time. It was demanding the student think laterally about these results – the sort of skills the university professor told me he looks for in his post-graduate students but they are sadly lacking in.

It should be noted at this point that the genesis of some of the most significant discoveries in science have been from experimental work that generated unintended outcomes. In the 1800s ether and nitrous oxides were being used at parties as 'laughing gas'. It was noticed at the time that these combinations of chemicals also masked pain and the first anaesthetic was born. Along similar lines, Sir Alexander Fleming left his bacterial culture unattended for a period only to return to find a mould growing on it. He noted that this mould impacted the growth of some of his bacteria, destroying his experiment. Annoyed, and his work ruined by the mould, Fleming discarded his bacterial culture. However, several years later, Howard Florey, who worked for a period at the University of Adelaide, isolated the chemical from the mould, *Penicillium*

notatum, and named it Penicillin – our first ever antibiotic, which has since been used to save millions of lives.

So what can we do?

The SACE Deconstruction and Design experiments provide an excellent opportunity for the boys to develop these attributes, as do the IAs in the IBDP. However, the boys complete these in their final years of secondary schooling – is this too late?

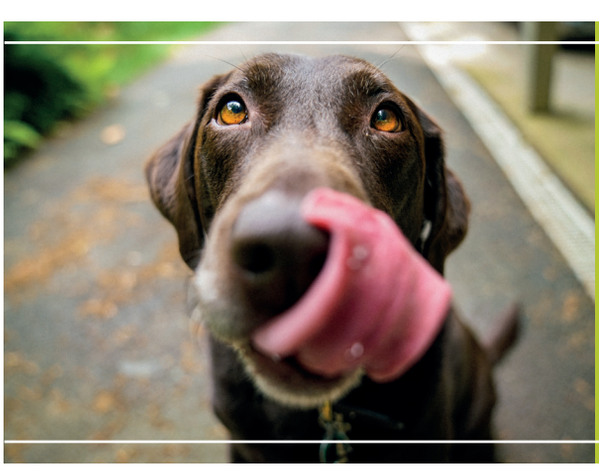
For the last few years at Prince Alfred, our Year 7 students have competed in the Science Investigation competition. This competition demands that the boys design an experiment of their choosing and present their methodology, results and conclusions in the form of a poster. They then present this to a panel of judges in a similar manner that a poster would be presented at a Science conference. It is not uncommon for the boys to obtain quite strange results in this activity, which they have to think quite deeply about in order to explain. Whilst this is done at Year 7 level, it is possibly the most authentic practical activity our boys do in their years of senior schooling. More activities like this are needed.

Along similar lines, I feel we need to incorporate short experiments in middle school science lessons. Most of these should still be related to the content that has been explicitly taught, others not so that students develop the ability to think their way through the results they observe in class when they have no real idea of the results they should obtain prior to beginning the activity.

We could also look to incorporate more 'front ended' experimental work – completing experiments before content is taught. Students could then offer possible explanations for what they are seeing. Most of these explanations will ultimately be determined to be incorrect, however, such an approach could foster an atmosphere whereby students are comfortable in making mistakes in this regard. Whilst this would be a benefit of this approach, as a teacher, one would need to be wary that it does not lead to misconceptions arising – there remains no substitute for the explicit teaching of concepts in a Science classroom.

I feel we need to create more opportunities for boys to make mistakes, so that it becomes more of a norm than an exception. Practical work provides an ideal medium for this, however, such opportunities do not need to be confined only to this area. It can also be fostered through robust class discussion for example. It is my hope that in creating such an environment our students will be much more comfortable and willing to make mistakes and develop the ability to think more laterally from them. These are the sort of skills that are needed if one is to embark on a career in Science, which must surely be one of our aims when educating our boys.

Ultimately, this will mean our students will learn a great deal from their mistakes, which will serve to keep Henry Ford very much content.



Dogs can dream like us, since they replay moments from their day while fast asleep.

Photo by James Barker on Unsplash

Don’t Forget Liberty in the Pandemic

Words by Ruben Japp

Thought starters

The pandemic shall be an experience that we all will remember for many years to come. The effect that it has had upon all of our lives is historically unmatched and could hardly have been predicted. But how has the pandemic response impacted us all? Will mankind be changed for good? I will examine and give my opinion on the vast impacts of the many facets of this pandemic response.

Lots of the major effects of the coronavirus have arisen from the “stay at home” or “lockdown” orders that have been enacted across the world. These are some of the greatest restrictions of freedom that have been seen anywhere, across the world, at any time. Billions of people have been told that they can’t leave the house to do the things that they normally do, the things that they love doing. Governments around the world have decided which of *your* activities you can continue doing. Is this the beginning of more government control on all aspects of personal life?

Moreover, many people around the world can’t see their family and friends. There are family members who have not seen each other for over a year and a half, (some of them at our school), hospital patients with no visitors, funerals with no attendees, and many confined largely to their own homes. Imagine being told in 2019 that the government would forbid people from seeing their parents and grandparents during their final days. No one would have believed it, yet here we are. And with loneliness already being a huge problem in the elderly, it is difficult to think about the effects that such a long period with reduced travelling and interaction is going to do to so many around the world.

Also a significant product of this, are the effects upon the cognition of our infants. With little interaction with others their age, rarely leaving the house for over a year during the key stages of their development, and missing out on learning key social cues from facial expressions due to masks, how can babies’ minds be expected to develop properly? The experiences gained from social interaction and ‘discovery’ of the outside world have been severely restricted for such a long time, that IQ scores in infants born in the last few years have been significantly lower than the same age group in previous years, by more than 20 points. Will this generation, of babies born just before and during the pandemic, ever regain normal social and interaction skills, and resume normal cognitive development? We must dearly hope so.

One of the largest negative effects of this pandemic is the number of people who have been told that their business is ‘non-essential.’ Imagine the number of small business owners who have worked extremely hard to make their business dreams come true, only to have successive lockdowns and various other restrictions imposed upon them during this time that have adversely impacted their income. In America, at least 30% of all small businesses have had to close over the last 18 months. It is difficult for us to imagine the pain that must come with seeing the product of your business dreams, that you have worked so hard to make successful, or an intergenerational family business, deemed ‘non-essential’ and forced to close. Years of hard work from so many, lost.

Moreover, multitudes of employees upon whom many more were dependent for food, money, shelter and support, were told that their job was ‘not essential’ to

society. Is not every job of every single person who supports his family, and who contributes to the functioning of a business and society, absolutely essential?

Another possible outcome of all of this is the negative effects of increased technology usage. Think of all of the people who have been made to have all of their social interactions through video conferencing for more than a year. There must be negative side-effects to this that we have yet to witness. Worse still is the children who are stuck at home, unable to attend school. In a generation that already suffers from the effects of computer and internet usage and addiction, it is almost certain that they will suffer more adverse consequences as a result of this. We must hope that our children can recover their social and mental skills, and overcome the problems of excessive internet usage, that have arisen from this combination. Hopefully, human nature is not changed for good.

It must be noted however that the lockdowns we have experienced have clear benefits. Western Australia and South Australia, known for their almost immediate lockdowns due to relatively small amounts of cases, have had some of the lowest infection numbers per capita. The strategy of dealing a quick blow to community transmission seems to have had positive effects in these states of stopping further infections in their tracks, thereby allowing residents to return to an almost normal level of freedom. Contrast this with the half-hearted approach of other states, who initially resisted lockdowns, resulting in rapid spread ultimately leading to the removal of freedoms for far longer periods of time. This would suggest that more immediate, strict restrictions such as lockdowns have clear community benefit. Several industries have also grown as a result of the pandemic, such as take-away

food, online shopping, delivery and couriers, as well as home renovation firms, which have all seen an increase in business as a result of more people being prevented from leaving the house as much as previously. With many people working at home, the time spent on home improvement, quality time with family, and a reduction in commute time has been a positive for many. A pause from the daily stresses can do no harm, and that has been provided to many people by the lockdowns, as well as an improvement in air quality in some locations.

Despite these positives, it does remain my belief that the government should retain a back seat in controlling people's lives as much as it has. If the pandemic has taught us

anything, it should be that we should not let the government put in place such vast restrictions upon our liberty. A combination of factors has allowed it to happen this time, but we shouldn't let it happen again. Our businesses, education, hobbies, family and social gatherings, travel and so many other things have been seriously curtailed. While, of course, all can take measures deemed appropriate by oneself to prevent catching the virus, it is my belief that the government should step down from its self-appointed role as 'disease warden,' and allow things to run their course. Whilst it could be argued that the government has a responsibility to protect the community, there are multitudes of things from which we cannot be guaranteed absolute safety that we continue to do and interact with on a daily basis. These include many diseases, and this one should be no different. Reinstate freedom and liberty, instead of pampering the public, is what I believe the government should do.

In conclusion, how the pandemic affects us is up to us. If someone were to suddenly take away all liberties, we would certainly notice, and rightfully be very angry about it. But, when it happens slowly, people seem to justify it. Remember, you are part of 'people.' Think about the standards that you walk past, because that is the standard you accept.

"Any society that would give up a little liberty to gain a little security will deserve neither and lose both."

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Bananas are curved because they grow against the pull of gravity. They start off hanging downwards, but as they get bigger they grow upwards in search of sunlight and end up with a curved shape.

Image by Mahdis Mousavi

How Anti-Viral Enzymes Transform Pre-Leukaemia Stem Cells into Leukemia

Words by Billy Trim

Biology

Despite the leukaemia death rate remaining relatively constant in the last 20 years, the incidence of the disease, a form of blood cancer, has been steadily increasing. (Figure 1). This trend has prompted investigations into the science behind the condition's causation. Interestingly, it has been found that both viral infections and space travel trigger inflammation and the enzymes APOBEC3C and ADAR1. These two enzymes have been known for some time to be precursors that trigger pre-cancer stem cells to develop into cancerous cells. Hence, developing ways to inhibit these enzymes by replicating methods used on astronauts may lower the cancer risk for people on Earth.

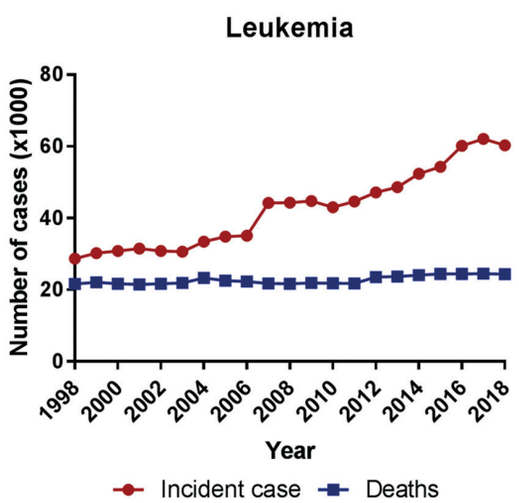

Figure 1 shows the incidence and deaths of leukemia over the past 20 years.

All specialised cells originate from stem cells. These unspecialised cells have the ability to renew, differentiate and self-generate, thus playing an essential role in the health of humans. However, this continuous reproduction can become dangerous if the stem cells 'go rogue', causing them to develop into malignant blood cancers like leukaemia.

Leukaemia leads to a rise in white blood cells in the body. These abnormal white blood cells would usually fight infection but due to their overproduction, they affect organ function from the lack of red blood cells to supply oxygen, platelets' deficiency to clot blood, or lack of normal white blood cells to fight infection. 60,300 people are expected to be diagnosed with leukaemia this year, and over 382,000 people live with leukaemia or are in remission. A leukemic stem cell (LSC) is functionally defined as a normal stem cell that undergoes a mutation, giving rise to an abnormal cell. While normal stem cells continue to differentiate, the mutated stem cells have properties similar to the normal stem cells, however, they differentiate into hematopoietic stem and progenitor cells carrying the defects.

APOBEC3C is an enzyme found in a cluster thought to result from gene duplication on chromosome 22. The enzyme's function involves RNA editing roles in growth and cell cycle control. It also encodes the protein Adenosine deaminase (ADAR1) which is an RNA binding enzyme that functions in catalysing the deamination (removal of an amino group) of adenosine to inosine in double-stranded RNA.

The body's inflammatory response is a defence mechanism that occurs when tissues are injured. The damaged cells release chemicals called cytokines that cause blood vessels to leak fluid into the tissues, causing swelling. As illustrated by Figure 2, pre-leukemia stem cells (pre-LSC) are affected by the APOBEC3C cytosine to thymine deamination, which fuels the hematopoietic stem and progenitor cell (HSPC) expansion, which promotes the production of inflammatory cytokines. These cytokines then trigger ADAR1 formation, which edits or switches the STAT3 gene, ultimately leading to pre-LSC transformation to leukemic stem cells.

Researchers at University of California San Diego School of Medicine have worked to understand what causes stem cells to transform into cancer stem cells and how to stop this. Their research indicates that the enzymes APOBEC3C and ADAR1 work together to turn pre-LSC into LSC. With APOBEC3C promoting the proliferation of pre-LSC, and ADAR1 becoming "*overzealous in its editing, skewing gene expression in a way that supports LSCs.*" These enzymes react to

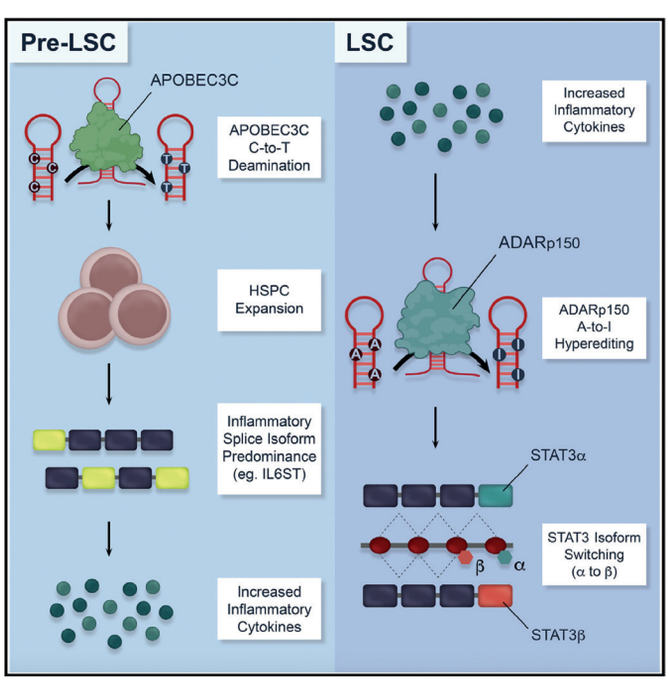

Figure 2

the body's inflammatory response to viruses, act to increase the cytokines at the infection site and increase the pre-LSC's editing rate, eventually turning them into LSCs. The scientists then furthered this by discovering that "*when the researchers inhibited ADAR1 activation or silenced the gene in patient cells, they were able to prevent the formation of LSCs*." Thus, by inhibiting ADAR1 with existing medications, neratinib or ruxolitinib, the conversion of pre-LSCs to LSCs was was reduced.

This major development is significantly beneficial to society. Primarily, identifying the enzymes and their role in the transformation from pre-LSC to LSCs meant enhancing the science behind blood cancer initiation and a better understanding of the human body. Additionally, the discovery of these enzymes reveals opportunities to combat leukemia, seen in the use of existing medications (neratinib and ruxolitnib) to inhibit these enzymes, slowing the spread of the disease.

The development of how leukemic stem cells are derived from stem cells has been heavily influenced by previous scientific understanding, technology, and economics. This technological and economic influence is evident in the further research of the science team's focus on APOBEC3C and ADAR1 and their roles in cancer cells. The NASA-funded project helps society's fight against leukemia as it means that by large corporations supporting the project from an economic perspective, financial constraints and limitations can be surpassed. In addition, this economic support made by NASA and others such as the National Institute of Health and the California Institute for Regenerative Medicine, mean that money can be invested so that once developed and offered to the public, these procedures can be completed on a larger scale, making them quicker, cheaper and therefore more accessible to those who are economically disadvantaged.

The technological influence of this development is also apparent. Whilst providing economic support, NASA is also aiding the project by providing scientists access to a stem cell research laboratory as part of the International Space Station (ISS), which is the first of its kind. This meant that the NASA Twins Study (a comprehensive biological comparison of identical twins, one spent six months aboard the ISS and one on Earth), could be further investigated in relation to their stem cell development. This led to the discovery of an increase in inflammatory growth factors, immune deregulation, and pre-cancer mutations in the astronaut's blood upon his return. This led researchers to conclude by that if APOBEC3C and ADAR1 inhibitors can be developed as a risk mitigation strategy for astronauts, then pre-cancer stem cell generation in low-Earth orbit and on deep space missions can be prevented. Based on these findings, researchers are now also interested in further exploring the links between inflammation and cancer.

Potential applications of this new knowledge would most likely be seen in human testing of the medications on inhibiting these enzymes, which, if successful, could lead to the treatment of leukemia patients. This science could also be applied to other stem cells affecting cancers such as lymphoma, neuroblastoma, and multiple myeloma, as they also have stem cell transplants as a recovery method.

Conversely, possible limitations facing this ongoing development include reliance on external funding. If these companies were to reduce the financial aid, research would slow and affect the efficiency of patient treatment. Another limitation of this recent progression is its minimal investigation to this point, meaning that these processes have not been fully researched. The long term effects of these medicines on pre-LSCs and LSCs are unknown leading to ethical considerations. This means that these effective medicines have not been monitored regarding their prolonged effect on human stem cells. Additionally, the equity of access to by undeveloped and less economically privileged countries will limit ethical integrity.

In conclusion, the push to cure leukemia, catalysed by growing patient numbers, has advanced with the discovery of two enzymes APOBEC3C and ADAR1, that help transform pre-LSC to LSC. Ultimately, this significant scientific advancement could lead to further developments in the matter, with the aim of a potential cure for leukemia.

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CART-T Cells: Engineering Patients' Immune Cells to Treat their Cancers

Words by Dinan Perera

Biology

With approximately 9.8 million people dying each year from cancer, scientists and practitioners worldwide are responding by seeking new cancer treatments. Immunotherapies are prospective cancer treatments that modify a patient's antibodies to target cancer cells. Chimeric Antigen Receptor (CAR) T-Cell Therapy is a recent form of immunotherapy that has shown promising results in clinical trials for cancers like leukemia and lymphoma. Areas of biotechnology and nanotechnology have influenced the development and improvement of CAR-T cell therapy as an effective immunotherapy. Despite the promising application of CAR-T cell therapy for patients with haematological malignancies, the limitations of its side effects and social concerns raises questions of its role in society.

Cancer is caused by abnormal cell division that results in the deterioration of body tissues. The body's adaptive immune system fights cancerous tumours through the action of T-cells, which detect the Major Histocompatibility Complex (MHC) on cancerous cells and deactivate them by binding with surface receptors. However, cancerous cells can downgrade or mutate the MHC complex, inhibiting the T-cell's ability to identify and elicit a response against them.

CAR-T cell therapy is a form of adaptive cell transfer (ACT) which involves modifying patient T-cells via genetic engineering. T-cells in the patients' blood are extracted by leukapheresis, where blood components are selectively filtered from the body. Genetically engineered viral vectors inject a desired gene into the T-cell's DNA. Changing the genetic sequence in T-cells enables them to produce Chimeric Antigen Receptor (CAR) proteins which target tumour receptors. Therefore, CAR-T cells deactivate tumours without MHC restrictions, as CARs are specifically structured to be complimentary with tumour receptors. CAR-T cells are then cultured and multiplied, increasing the potency of immune response received by patients. These mature CAR-T cells are administered in patients and their side effects are monitored (Figure 1). Specialists may then use nanoparticle drug carriers to improve potency of response and deliver the desired gene to the T-cells.

Advancements in the field of nanotechnology have greatly influenced the model of CAR-T cell therapy in society. Conventional CAR-T cell therapy has limited response to solid tumours, as their microenvironment causes a formidable barrier to suppress T-cells. Nanoparticles are synthetic carriers which are injected in the bloodstream and deliver a desired gene to the T-cells to then produce receptor proteins for tumour cells (Figure 2). Current application of liposome-based nanoparticles has impacted CAR-T cell therapy by improving delivery of desired gene whilst evading the tumour's microenvironment. The Fred Hutchinson Cancer Research Institute designed nanoparticles which infuse receptors on CAR-T cells that bind with CD-19 receptor on tumour cells. Trials with Acute Lymphoblastic Lymphoma in mice showed that 90% of mice with nanoparticles entered remission and had significantly decreased tumour counts. Results showed that nanoparticles blocked suppressor cells in the tumour microenvironment whilst simultaneously stimulating key anti-tumour components of the CAR-T cells. Scientists believe programming nanoparticles to deliver multiple CAR's

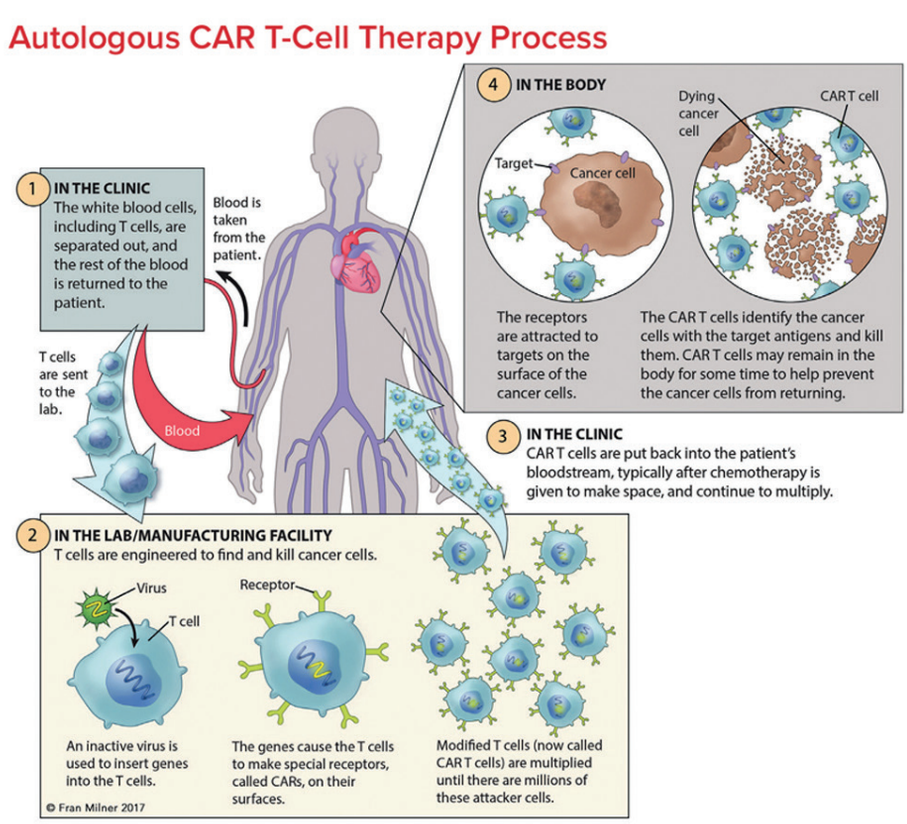

Figure 1: Stages of CAR-T Cell Cancer Therapy

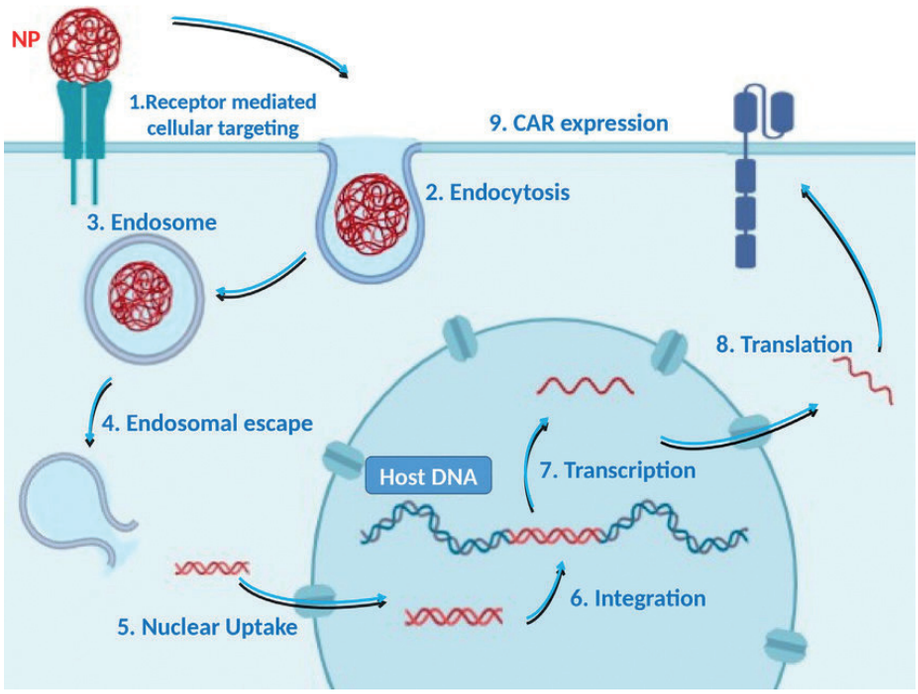

Figure 2: Process of using Nanoparticle in CAR-T cell Therapy

may improve the response of tumour cells via multiple angles. Ultimately, a greater understanding of nanotechnology and its application can impact the successful execution of CAR-T cell immunotherapy.

Gene-editing technologies such as CRISPR/Cas-9 have influenced CAR-T cell functionality. The body's immune response is regulated by the Programmed Cell Death Protein-1 (PD-1) pathway, which suppresses the activity of T-cells and down-regulates the immune system. CRISPR/Cas 9 technology can disrupt the inhibitory effects of the PD-1 pathway by silencing the PD-1 gene. In 2019, preclinical trials utilised adenine-base CRISPR technology to alter the PD-1 gene, where decreased expression of the PD-1 protein subsequently prolonged T-cell activity. The American Association of Cancer Research found that reducing expression of the PD-1 gene in anti-prostate stem CAR-T cells significantly improved their efficacy against tumours. Researchers extended CRISPR's influence to silence genes which disrupt inhibitory receptors or potentially produce universal allogenic CAR-T cells for treatments. The exploration of epigenetic modification methods has demonstrated the influence of technology on improving the efficacy of CAR-T cell therapy.

The application of CAR-T cell therapy has shown promise in treatment of patients with Acute Lymphoblastic Leukemia (ALL). ALL affects the bone marrow through the overproduction of white blood cells. Patients with ALL have limited options, as tumour cells are prone to reappear after treatment. Therefore, CAR-T cell therapy enables the body to gain an immunity and utilise modified T-cells to fight ALL. Axicabtagene Ciloleucel is a CAR-T cell therapy trialled for ALL patients with non-Hodgkin Lymphoma and showed recovery rates of 70%, where its unique cell structure reduced adverse side effects from treatment. Larger clinical trials led to the FDA approval of Tisagenlecleucel, showing 80% remission rate for ALL patients. Marta Coscia of Frontiers in Oncology commented that *"unprecedented CR rates achieved in almost all trials imparted the credibility to CAR-T cell therapy"*. CAR-T cell therapy has advantages compared with other treatments, due to its unique specificity for tumour cells and therefore decreased likelihood in damaging normal body tissues. The flexibility of intracellular signals by the T-cells, enables them to evade defence mechanisms employed by tumour cells. Evaluation of current understanding in CAR-T cell therapy reveals the desirable prospect of utilising this immunotherapy, where further studies should be conducted to confirm its general approval for ALL. Therefore, current application of T-cells in ALL indicates the prospective nature of it becoming a standard intervention.

However, the presence of adverse side effects has limited the approval of CAR-T cell therapy. T-cells elicit an immune response through the release of cytokines, messenger molecules which signal the T-cells to perform their function in eradicating the tumour. The expansion of CAR-T cells can lead to Cytokine Release Storm (CRS), where large amounts of cytokines are released into the bloodstream and cause severe organ dysfunction. Researchers believe that the CAR's structure and antibody affinity may have correlative toxic side effects. Concerns with CAR-T cells cross-reacting with normal antigens on non-cancerous cells and damaging healthy tissue resulting in the potential for patient harm. Furthermore, CAR-T cell therapy can cause 'insertional oncogenesis' where viral vectors are abnormally inserted in the T-cells genome and can become cancerous. Significantly altering the genome has raised ethical concerns due to potential changes in the patient's DNA. Concerns of researchers mishandling CAR-T processes, requires strong implementation of policies to regulate this treatment. Understanding of these biological processes are based on insufficient findings, where limitations have halted CAR-T cells therapy's role in society.

Economic considerations of CAR-T cell therapy have raised concerns of ensuring equitable access to these treatments. Individual cost of treatment is usually in excess of $350000 (Figure 3), however projected costs for additional associated care when managing side effects can reach $1.5 million. Kathleem Imbach at 'Gene & Cell Therapy' stated that *"CAR-T cell therapy and associated costs"* from complex manufacturing supply chain may make treatment to be *"unfairly stratified in socioeconomic lines"* due to the disadvantages towards those less financially stable. High-cost treatments and rapid deterioration of a patient's condition may disincentivise individuals in receiving potentially beneficial treatments. Greater involvement of government reimbursement schemes and subsidies of these treatments is required for CAR-T cell therapy to become financially reasonable. Ultimately, the commercialisation of CAR-T cell therapy should consider a patient's economic concerns and their ability to receive affordable treatment.

Additionally, the application of CAR-T cell therapy has been influenced by social demand despite the absence of clinical approval. The "compassionate use" policy in the US enables patients with life-threatening illnesses, like cancers, to participate in investigational trials without treatment approval. Therefore, some patients partake in these trials in the hope of accessing new therapies and may steer away from conventional treatment to their detriment. Firms who incentivise financial gain and deny distribution of treatment may experience public backlash. Therefore, the role of CAR-T cell therapy is presented with an ethical dilemma, as respecting patient autonomy and minimising patient harm from uncertain side-effects must be equally acknowledged. Ethical concerns may extend to the availability of treatment, where limited manufacturing sites may cause healthcare workers to make tough decisions on who receives treatment. Overall, current understanding of CAR-T cell therapy has meant manufacturing firms must manage public demand whilst also ensuring patient safety.

Deeper examination of CAR-T cell's role in society reveals the importance of manufacturers maintaining ethical standards and adhering to strict FDA requirements when approving the immunotherapy. Researchers at 'Gene & Cell Therapy' believe *"it would be preferable for CAR-T cell therapy to expand slowly"*, where scientists gain a better understanding of its health effects over time before approving treatment. The inception of regulatory bodies such as Switched Oncology, are examples of government institutions which address benefits and limitations of CAR-T cell therapy so that patients can make informed decisions. Ultimately, individuals in society should wait for conclusive findings in order to ensure optimal treatment in the future.

In conclusion, the development of CAR-T cell therapy has provided an alternative solution for patients dealing with some debilitating forms of cancer. Refining procedures and alternatives to these treatments stem from the influence of various technologies when improving its effect on patients. However, the limitations of its harmful side effects and concerns economically and ethically, imply that greater research is needed before it becomes a standard intervention.

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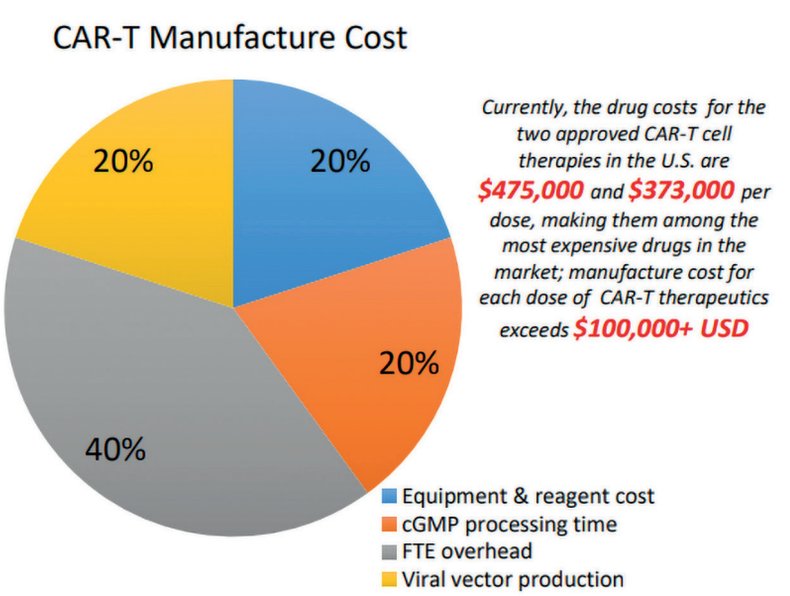

Figure 3: Manufacturing Costs of CAR-T Cells in America

Melatonin Synthesis and Pineal Gland Calcification

Words by Hyunseok Kang

Biology

The pineal gland's name derives from its resemblance to a pinecone. It is a very small neuroendocrine gland, weighing only about 100 to 150 milligrams, located in the brain's epithalamus. (Figure 1)

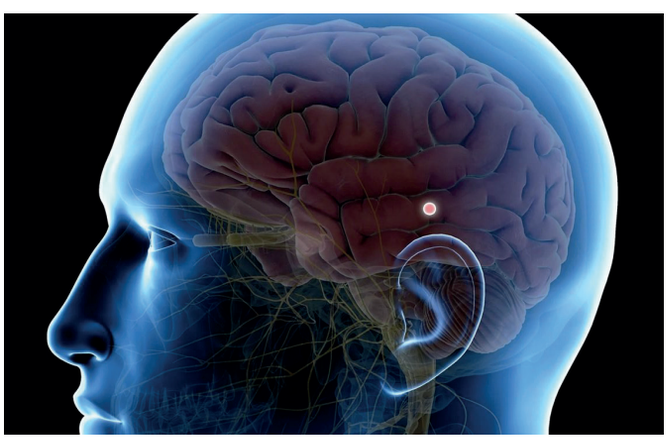

Figure 1

Its main function is to synthesize and release a hormone called melatonin, which regulates our sleep cycle. This is because when melatonin activates its receptors around the body, it induces bodily responses that encourage sleep and are thus associated with sleepiness, such as restriction of extensive nervous activity via inhibition of significant neurotransmitters such as dopamine. Figure 2 shows the structural formula of melatonin.

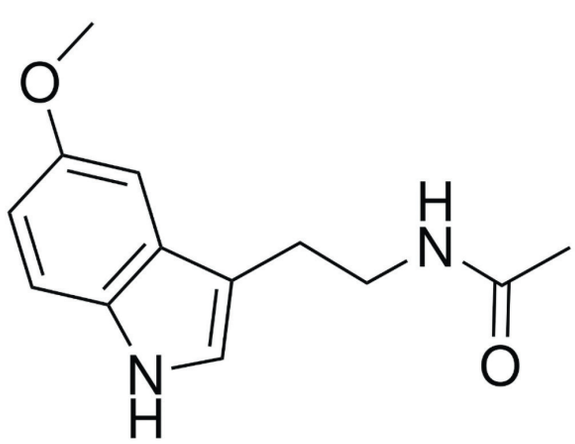

Figure 2: Structural formula of melatonin

The pineal gland regulates the release of melatonin as it receives neural signals from the retinal ganglion cells. These ganglion cells have photoreceptors, which enables it to inform the pineal gland about environmental light cycles, much like the activation and deactivation of phytochrome photoreceptors in plants enable them to gain information about their own environmental light cycles. To evaluate the specific biological mechanisms agonised by melatonin, the retinal ganglion cells that receive the stimulus send information to the suprachiasmatic nucleus. This is a region of the hypothalamus, which is an area of the brain responsible for controlling the body's circadian rhythm; a range of behavioural, physiological and mental changes that occur in response to light cycles. If there is light and hence the signal from the ganglion cells is positive, the suprachiasmatic nucleus releases butyric acid, inhibiting the neurons that signal to the pineal gland and disrupting melatonin synthesis. Conversely, if the signal is negative, meaning darkness, a neurotransmitter called glutamate is released, which facilitates the neural signalling to superior cervical ganglions which releases norepinephrine, triggering pinealocytes. These pinealocytes then promote the release of the enzyme arylalkylamine N-acetyltransferase, the first step in melatonin synthesis. Expressly, melatonin is a tryptophan derivative, and arylalkylamine N-acetyltransferase catalyses the transformation of 5-hydroxytryptamine, a simple tryptophan derivative, to N-acetylserotonin. The final step involves the transformation of N-acetylserotonin to melatonin via the enzyme acetylserotonin O-methyltransferase. Outside of the pineal gland, melatonin synthesis has also been observed in the skin, retina, bone marrow and in the placenta during pregnancy. However, the synthetic yield was not adequate to promote any significant melatonin receptor agonisms that would significantly affect one's circadian rhythm.

Outside of controlling our sleep, melatonin has also been associated with other health-promoting functions, such as boosting human growth hormone, prevention of macular degeneration, treatment of heartburn, and even as a factor in alleviating tinnitus symptoms. Although though the full extent of its physiological mechanisms relating to these functions are unknown, it could be comfortably said that melatonin is a critical hormone to maintaining homeostasis.

Given its significance in regulating our sleep, there are issues deriving from insufficient endogenous production of melatonin—naturally, related to a lack of sleep, or more generally a disturbance of the circadian rhythm. To combat this, melatonin can be orally ingested at therapeutic doses, with uses extending not only to disorders with issues rooted in a lack of sleep, such as jet lag and insomnia, also to issues related to too much sleep, such as narcolepsy.

Calcification occurs when there is extensive accumulation of Ca^{2+} in areas of the body. It is normally a benign condition when occurring upon hard tissue, such as bone. However,

it becomes highly problematic when there are excessive deposits of calcium on soft tissue such as arteries, cartilage and tissue, this can cause hardening that can impede its corresponding physiological functionalities. The relevance of this to the pineal gland is that the pineal gland is one of the most susceptible organs to this type of progressive mineral deposition, attributable to its high vascularity, with most adults showing a degree of calcification in their pineal glands. Outside of humans, other animals such as sheep, horse, rats, monkeys, chickens and turkeys also showed pineal gland calcification. Naturally, calcification of the pineal gland inhibits its synthetic capacity of melatonin, and is strongly associated with the aging process and aging-related diseases.

Interestingly, the pineal gland's connection to the aging process is not necessarily transparent, given the regulation of the sleep cycle does not seem to have an inherent relation to the rate at which metabolic pathways and overall bodily functions begin to lose efficiency. However, the connection is one that cannot be overlooked, and there are several extensive pieces of academic research to support the claim that this gland that primarily lends itself to controlling sleep has significant connection with aging. For example, it is well documented that there is a negative correlation between one's age and melatonin synthetic capacity, attributable to the desensitisation of receptors on the pineal gland, changes in gene expression as well as the gradual calcification. Moreover, a study published by Walter Pierpaoli and William Regelson in the National Academy of the Sciences Journal in 1994 examined the impact of pineal gland suppression on the aging process in rats. They found that aging was accelerated in young rats who had melatonin production inhibited via a pinealectomy, primarily in connection to an exponential increase in the accumulation of oxidative damage. Conversely, when healthy pineal glands were transplanted into old rats, and hence melatonin production was boosted, there was an increase in life expectancy. The same outcome was observed when the rats were exogenously administered with a relatively high dose of melatonin. This is only one of several studies that studied a similar topic. That being said, such an observation in other animals does not necessarily extend to humans, and extensive testing or experimentation has not been conducted to trial similar variables within humans. Overall, it seems an undeniable truth that a maintenance of the pineal gland's health and optimal functionality is within everyone's best interests, even only if for the sake of promoting healthy bodily responses to light-dark cycles. And it also seems that hindrance or prevention of such calcification of the pineal gland is a readily accessible and suitable means of preserving the health of the pineal gland.

So, how can this process of pineal gland calcification be slowed down, or even reversed to an extent? This extends to an area of research concerned with the "decalcification" of the pineal gland, otherwise also referred to as pineal gland rejuvenation. One of the most notable, as well as generally infamous, promoters of calcification is fluoride. Although the direct mechanisms as to why fluoride promotes calcification is not known, there is a very strong correlation between the presence of fluorides and extensive calcification, with its presence in aged pineal glands being higher by up to fivefold relative to other regions of the body. Therefore, it follows that decreasing one's exposure to excessive amounts of fluoride would be efficacious towards preserving pineal gland health. Moreover, there are also more direct methods of treatment, or prevention, of pineal gland calcification; a prime example of which is micro-dialysis. Micro-dialysis involves the collection of microscopic molecules in the extracellular fluid; the process of which grants access to the cellular environment of the pineal gland. This allows for the quantification of neurotransmitters, peptides, hormones, enzymes and many other potentially crucial molecules, including melatonin. To simplify the overall process, through exposure of the interstitial fluid in the pineal gland to ethylenediaminetetraacetic acid (EDTA), deposits of calcium can be directly dialysed. This is because EDTA acts as a vehicle for binding to adjacent iron and calcium ions. Alternatively, there are also the prospects of pineal gland transplants, or more minimally, an injection of young pineal gland stem cells into small decalcified regions of aged pineal glands.

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Although you cannot see oxygen in its gaseous form, it is actually a light blue colour when in a solid or liquid form.

Image by James Thornton

Messenger RNA vaccines; Can they protect us from disease?

Words by Lachlan Moore

Biology

The current global Covid-19 pandemic has sparked a worldwide effort to find a safe and viable prevention method that will inhibit the spread of the virus. This has influenced the production and testing of Messenger RNA (mRNA) vaccines in comparison to the traditional antigen vaccines, with hopes they will prevent the contraction of the virus. The recent developments of the mRNA vaccine have been promising and a worldwide roll-out has begun. Scientists also hope in the future the mRNA vaccine technology could also be further developed and trialled to be used to treat other diseases and viruses.

mRNA is produced during the first stage pf protein synthesis in the nucleus of the cell – transcription. The DNA is unzipped by RNA polymerase allowing for the mRNA to be coded from the DNA. The mRNA then leaves the nucleus and travels to the ribosome where it will undergo translation where it will code for the sequence of amino acids to form a polypeptide chain *(Figure 1)*.

Traditional vaccines contain weakened or dead strains of the pathogen which triggers the immune response of the body. As a result, the body produces antibodies to these antigens to help fight off the virus that has entered the body. mRNA vaccines are a combination of these and the properties of each are utilised to make an effective vaccine. Once the vaccine is injected into someone the mRNA it contains is taken into the cell and is translated on the ribosome to produce viral antigens. The antigens then alert B cells to produce antibodies that help destroy the antigen. In addition to this antibody production, the immune response will also produce memory T and B-cells that persist in the body to aid in a quick eradication of the same antigen if it was to enter the body again.

In its present state, the mRNA vaccine has shown to elicit a smaller T-cell response, however, this is not a concern as the role of the vaccine is to prevent the antigen from entering the cell, hence T-cells are not as critical to this aspect of the process. Covid-19 or SARS-CoV-2 is a highly contagious virus that affects the respiratory system. The small protein spheres in its outer coat are covered in spiky receptors to protect the RNA required for the virus to replicate. The virus attaches itself to a protein in the surface of the host cell (ACE2) causing a chemical change within it that allows the virus to enter the cell. Once inside the virus hijacks the cell and it begins to translate its RNA, producing thousands of new viruses. The cell then bursts, and the viruses spread around the body into new cells to begin the process again. The current Pfizer/Bio-Tech and Moderna vaccines both currently require an initial injection which prepares the immune system and then a booster dose three to four weeks later, which boosts the immune response so it is ready if a patient was to become infected.

The current Covid-19 pandemic has had a major influence on the development and trialling of mRNA vaccines. At its peak in the USA, there was in excess of 250,000 confirmed cases daily of Covid-19 and it looked as if it was going to continue to rise (Figure 2). mRNA vaccines were ideal to combat this rapid spread, given that they can be produced at a much faster rate than traditional vaccines. This allowed them to be distributed more quickly, resulting in a significant reduction in daily cases in the US to approximately 60,000 half that seen previously (Figure 2).

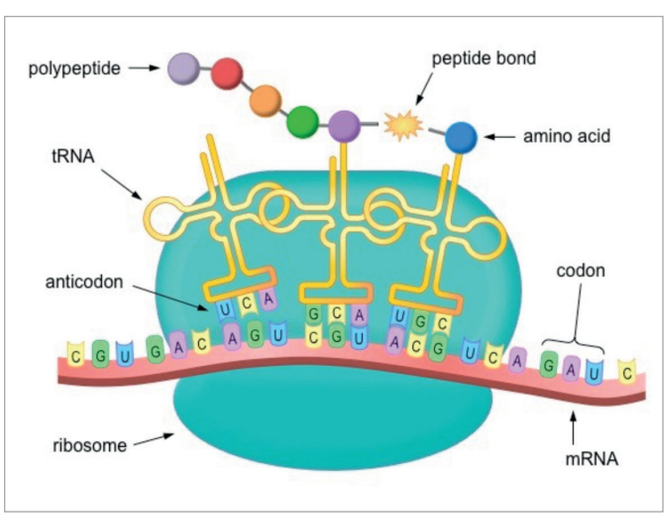

Figure 1: Diagram of the Traniation process in the ribosome

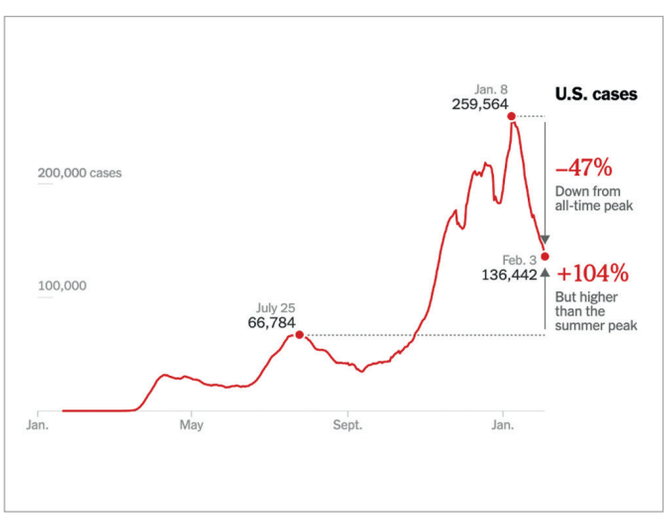

Figure 2: US Covid-19 cases 2020-21

Figure 3: The storage required to house the Pfizer/BioTech Vaccine

The production of mRNA vaccines has also been influenced by previous epidemics, such as those related to SARS, Ebola, avian and swine flu, and Zika. After a record number of influenza cases in 2019 with over 300,000 Australians contracting the virus (the highest number of yearly cases to date), there are hopes that the mRNA vaccine will have a major influence in reducing this figure much like it did with Covid-19 in the US. The vaccine will also play a major role in the re-opening of international borders allowing global travel to take place once again. Some predictions suggest that travel may return to normal in 2023 or 2024, once herd immunity has been achieved (70-80% of the world is vaccinated).

The use of mRNA in vaccines was first tested in the 1990s and has continued to be tested and trialled to the present day, however with little focus or push for its further development. The pandemic has rapidly increased this trialling and development with Pfizer and BioTech beginning clinical trials in July of last year. The vaccine was initially developed and tested on animals to make sure it was safe for human use so that a clinical trial could be conducted. Phase 3 of the trials (the final stage) involved 42,000 people, half of which received the vaccine, and the other half received a placebo salt and water mixture. Of the 170 participants that became sick with Covid-19, only 8 were in the vaccine group, which indicates the vaccine has a 95% efficacy. This concluded the final stages of the vaccine's development as it was then deemed safe for use (subject to each country's regulatory approval) and is now being rolled out worldwide. There are still however further developments scientists wish to make with the vaccine to make it more accessible and easier to use for nations across the world. In its present form, the Pfizer/BioTech vaccine needs to be stored at -70°C *(Figure 3)*, which drastically limits the ability of many countries to use the it as they don't have the facilities required.

Scientists are currently working on producing a new vaccine that can withstand warmer temperatures, as well as increasing its shelf life allowing it to be accessible worldwide. There are also trials into removing the secondary booster injection, so only one dose is required. This would allow the speed of the vaccine rollout to significantly increase and would also remove the chance of people skipping their secondary booster. This would allow herd immunity to be achieved more quickly, hence enabling the world to return to its normal sooner.

Although the vaccine is likely going to allow the world to return to what it once was, there are still limitations and ethical issues related to it. Specifically, the lack of knowledge that has been acquired as to what the possible side effects of receiving the vaccine raises ethical concerns. The vaccines are designed with relatively new technology, which we still know little about, which had also not been approved in any vaccines up until this point. Presently ongoing surveillance is the only method to be able to track the potential side-effects of the vaccine, however, it is likely to be too late if one is discovered as the majority of the world will have been vaccinated at that point.

Apart from the sheer scale of production required, a limitation of the current vaccine is the accessibility of it due to its requirements for storage and use, limiting the rate at which herd immunity can be achieved. There are also questions posed as to who will receive the vaccination first and how it will be distributed among communities. The cost of the production and distribution of the vaccine will also be questioned with an estimate that the entire pandemic will cost between $8.1-$15.8 trillion worldwide.

In conclusion, the use of mRNA vaccines as a prevention method to stop the spread of Covid-19 is the most viable option now and in the future. If the necessary changes are made to the vaccine allowing it to be more accessible to everyone across the world, herd immunity will be achieved at a much faster rate allowing the world to return to its pre-Covid state. Although they are still currently limitations and ethical issues surrounding the vaccine that require careful consideration, stopping the spread of the virus to save millions of lives should be the main priority, hence people should get vaccinated if possible.

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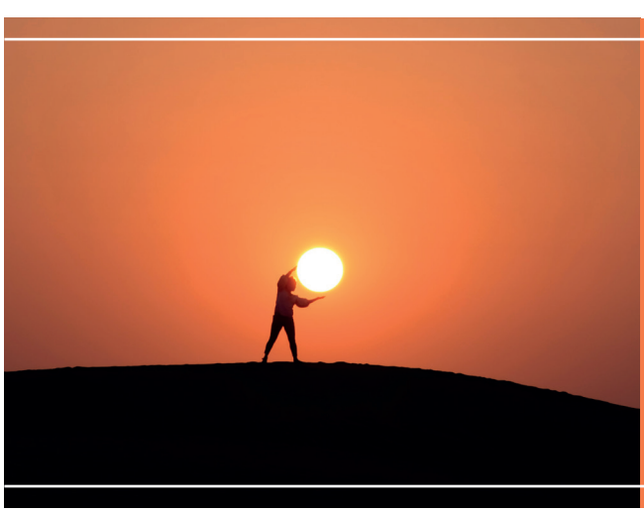

1 million Earths could fit into the Sun.

Photo by Selvan B on Unsplash

DNA Origami and the Treatment of Cancer

Words by Lucas Bernardi

Biology

In 2021, Australia is expected to diagnose over 150,000 patients with cancer, and over 50,000 residents will lose their lives to the illness. To combat the increasingly significant issue, scientists are continually identifying new cancer treatment techniques which are quicker and more effective than traditional methods. One of these newly established techniques is DNA origami, which involves the folding of DNA to create specifically shaped structures which are used to deliver cancer therapy drugs directly to cancerous cells. This review will investigate the social, economic, cultural and ethical factors which heavily influenced the advancement of this technique.

DNA origami is the process by which a long single strand of DNA is combined with hundreds of short DNA strands called staples to create specific shapes which can carry out a multitude of functions. Scientists have recently synthesised a specific type of DNA origami which is designed to effectively deliver cancer treatment to patients, without the harmful side effects presented by common treatment methods such as chemotherapy. Scientists manufactured an octagonally shaped DNA molecule, which is intentionally shaped to allow for high nanoscale stability, whilst also containing a large open space in its centre which can hold adequate quantities of anti-cancer drugs. The creators of this method discovered that doses of drugs can be placed inside the open space, and then locked inside to prevent the drug from escaping before it can reach the cancerous cells. As shown through Figure 1, this space can only be unlocked when it received key signals, in this case a malarial derived enzyme called *Plasmodium falciparum* lactate dehydrogenase (PfLDH), releasing the stored drugs. The molecule can hence be specifically coded to only open when it has reached a cancerous cell within the body which has the right complimentary key to open the box.

This method allows for direct delivery to cancerous cells, avoiding the exposure of healthy cells to toxic anti-cancer drug molecules which can prohibit efficient cell function. This is unlike traditional methods such as chemotherapy which

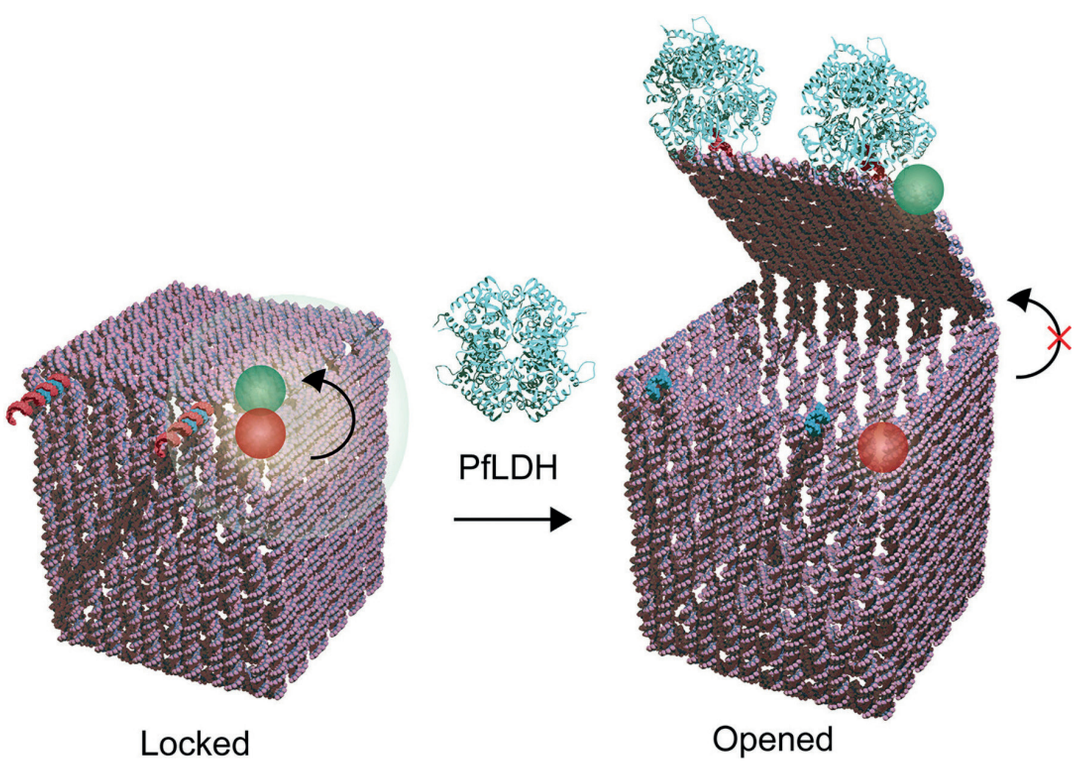

Figure 1: How DNA Origami is unlocked with certain signals

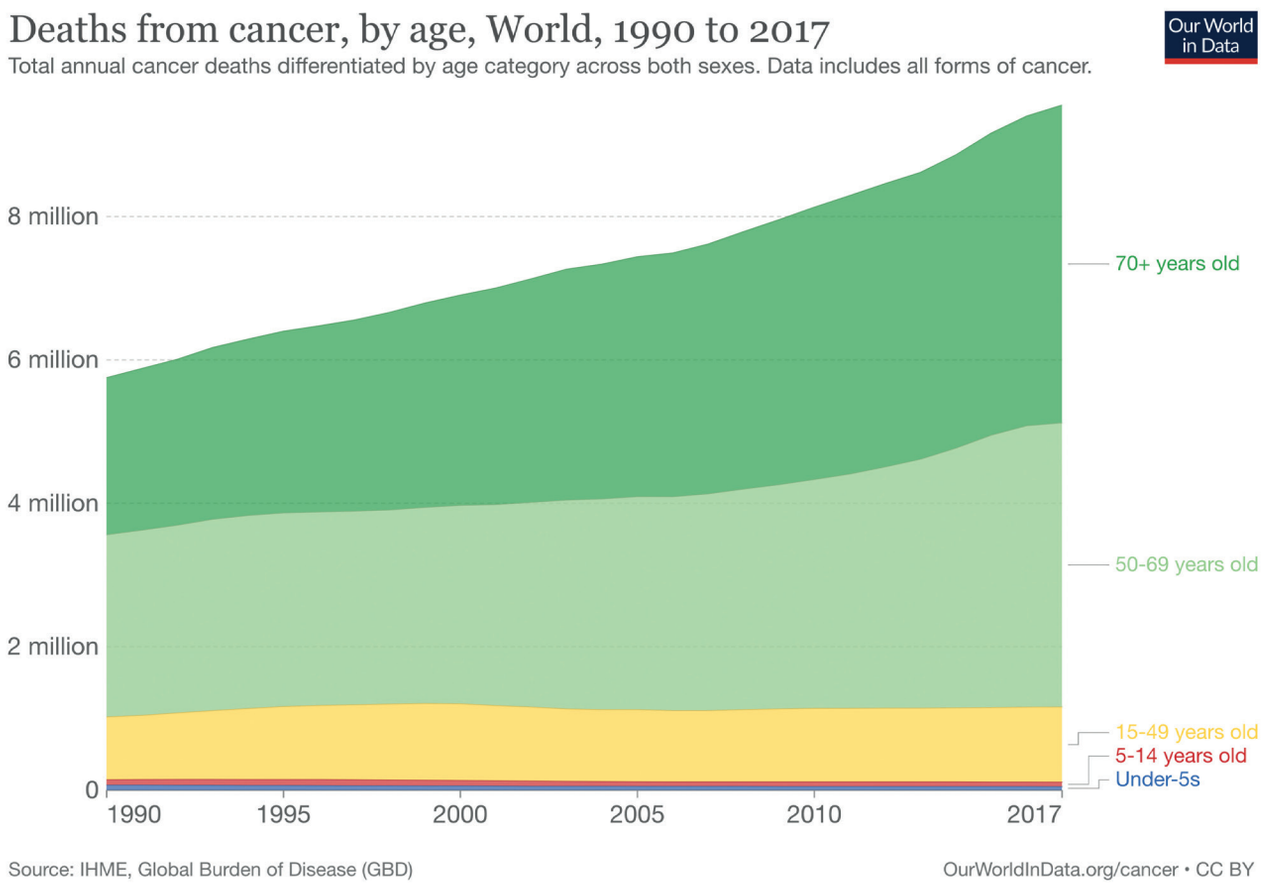

Figure 2: The number of worldwide cancer deaths within separate age groups charted over time

attack an entire area within the body and destroy many healthy functioning cells. This means that the DNA origami drug delivery method does not have such significant side effects as chemotherapy, leading to a more enjoyable treatment. The lack of requirement for recovery after each treatment session also means the process will be quicker for the patient overall. Additionally, because the molecule can be coded to suit particular types of cancer, the method is potentially applicable to any cancer patient.

In order to prevent the structure from denaturing in the harsh conditions of the body, the entire structure was also coated with peptoids, which bind to the backbone of the DNA, to protect the structure from deteriorating within the body and releasing the drugs prematurely.

Several social, economic, cultural and ethical factors played a key role in forcing the conception of peptoid coated DNA origami. One of the most significant of which included the reputation of cancer as a prominent disease which required immediate action from the medical field to mitigate. Cancer is considered to be one of the leading causes of death worldwide and as seen through Figure 2, the number of worldwide cancer deaths has increased steadily across most age groups over time and is predicted to continue in this trend.

The rising number of cancer patients globally inevitably led to heightened social pressures on the medical industry to design new and innovative cancer treatment methods which can attempt to limit these undesirable deaths and stop the increasing trend. This influence eventually led to researchers discovering the application of peptoid coated DNA origami as a proficient cancer treatment method.

Another significant factor which influenced the creation of peptoid coated DNA origami was the presence of substantial issues within current mainstream cancer treatment methods. Currently, chemotherapy is considered as the most commonly used cancer treatment method globally. However, one of the most critical issues with this method is the fact that the chemical exposure is not specific to only cancerous cells, causing many healthy cells within the surrounding regions to become damaged and lose their functionality. Damage to healthy cells can thus cause side effects such as: hair loss, infection, nausea and vomiting, constipation, diarrhea, urine and bladder changes, kidney problems and fertility problems, which can torment patients for years. The specificity of this new technique has the potential to mitigate these side effects almost entirely.

The final and most significant factor which heavily influenced the advance of peptoid coated DNA origami was the devastating economic impacts of cancer. The direct costs of cancer are high for both the patient receiving cancer treatment, the hospital administering it and society as a whole, which places a burden on the entire global economy. The Agency for Healthcare Research and Quality (AHRQ) estimated that in 2015 alone, cancer cost the US economy over $80 billion dollars. Traditional cancer treatment methods such as chemotherapy can be extremely expensive for patients, costing up to 12 thousand dollars per treatment session. With the patient unable to afford such costs, much of it is passed on to governments via the public health system.

The increasing fatality rate from the disease has also placed pressure on the medical field to find a quicker treatment method which would create a more affordable procedure.

Cancer patients can also take up valuable space in hospitals for many weeks, adding further to the financial burden created by this disease. The extended periods of time spent by patients in hospitals inevitably led to a need for a quicker treatment method, to free up spaces in hospitals and save money.

Additionally, when undergoing cancer treatment, many patients find themselves unable to work, decreasing the size of the workforce within a country, causing decreases in production and GDP, which slows the economic expansion of a country. The necessity for a sustainable workforce hence put further pressure on the medical field to create a method of treatment which was quicker, getting individuals back into the workforce faster.

The noteworthy applications of peptoid coated DNA origami have the opportunity to greatly influence and progress our society. Peptoid coated DNA origami's ability to treat cancer patients by specifically attack cancerous cells, without harming healthy functioning cells, would allow for cancer treatment to be more sustainable in every way. Using this as a mainstream cancer treatment process would be far cheaper, quicker and more effective for both hospitals and recipients. Along with this, the treatment would have fewer physical impacts on the patients, creating a far more enjoyable experience. By creating a completely new treatment method which revolutionises the industry, more people would be able to receive access to treatment and recover from their diagnosis of cancer. With more people recovering from the illness, this new treatment would inevitably cause a substantial reduction in cancer deaths globally. A reduction in cancer deaths would then create social benefits surrounding fewer families losing loved ones, and economic benefits surrounding increases in workforce sizes within countries and further GDP gain. However, one of the major limitations of this technique includes the lack of testing for human subjects. Before this method can be used for general practice, it must first be tested thoroughly to assure it presents no harmful side effects for recipients in both the short and long term.

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Babies actually have around 100 more bones than adults do.

Photo by Filip Mroz

Nanomaterials - Twenty First Century Cancer Treatments?

Words by Allan Hsi

Chemistry

The novel properties of nanomaterials that may provide benefits to society also raise concerns about how engineered nanomaterials may interact with human and other biological systems.

After cardiovascular disease, cancer is a significant cause of death in the world (Figure 1) and it is the responsibility of scientists to help treat those in need. Scientific understanding of various nanomaterials and their unique properties, combined with a rising need for new cancer treatments have allowed for various new technologies such as cancer eliminating gold nanoparticles, drug delivering nanocapsules and quantum dots to be applied in cancer treatment. Moreover, the discovery of such technologies has also prompted the assessment of social and economic considerations.

Gold nanoparticles (Figure 2) have allowed scientists to develop an alternative treatment for cancer which is less damaging to patients compared to conventional treatments such as chemotherapy. Particles of gold which are over 10nm have unique light absorption properties which make them ideal for photothermal therapy (PTT- Figure 3), a therapy that utilises laser light to heat agents present within tissue to damage it. Gold nanoparticles are highly absorptive of light and through photothermal therapy, can convert the radiation directed towards it into heat and eliminate cancer cells. Furthermore, the nanoparticles can be modified to have a higher tendency to accumulate within tumour cells in which PTT can be used. Through a new understanding of the properties of gold nanoparticles, scientists have been able to develop treatments such as PTT, which serve as effective substitutes for older treatments such as chemotherapy, which are often ineffective and harm patients. Rather than widespread treatment which affects healthy cells, the gold nanoparticles can be specifically made to accumulate in the target cells and therefore only malignant cells will be damaged, which maintains the health of the patient and reduces side effects such as hair loss. Furthermore, the efficiency of gold nanoparticle cancer treatments and improved quality of life for cancer patients produces more productive workplaces. Patients are able to return to their workplaces faster, allowing businesses to operate more effectively and therefore earn more money which is redirected back into the economy and funds all facets of life. More specifically, it can fund the research of more

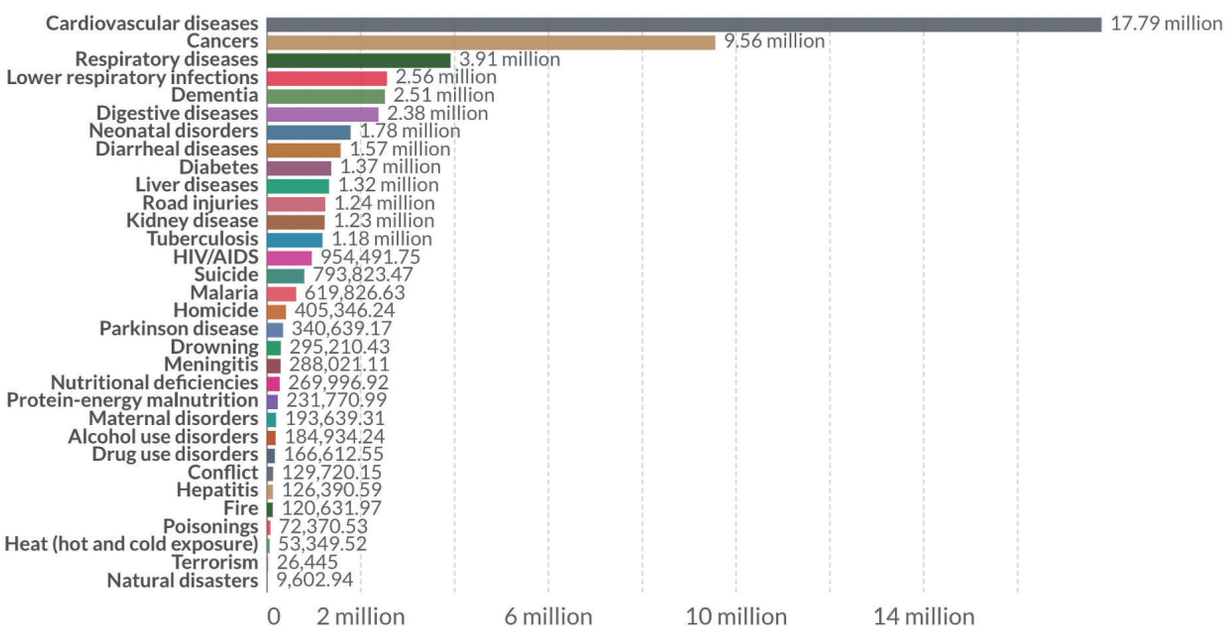

Figure 1: Number of deaths by cause, World, 2017

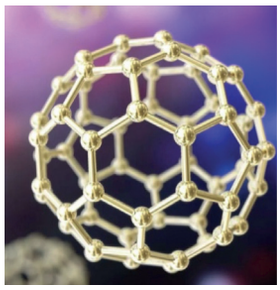

Figure 2: Crystallised gold nanoparticle

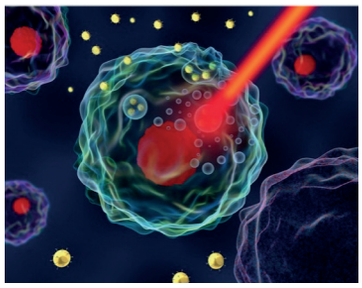

Figure 3: Stylised image of photothermal therapy using gold nanoparticles

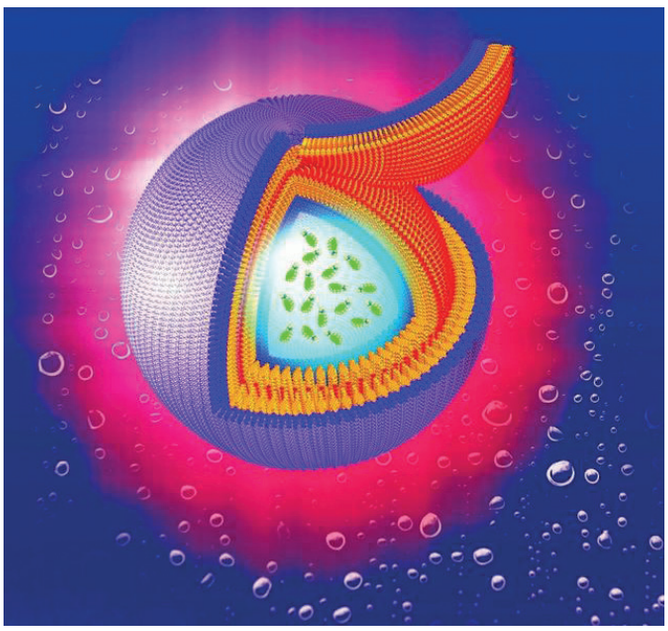

Figure 4: A nanocapsule cross-section

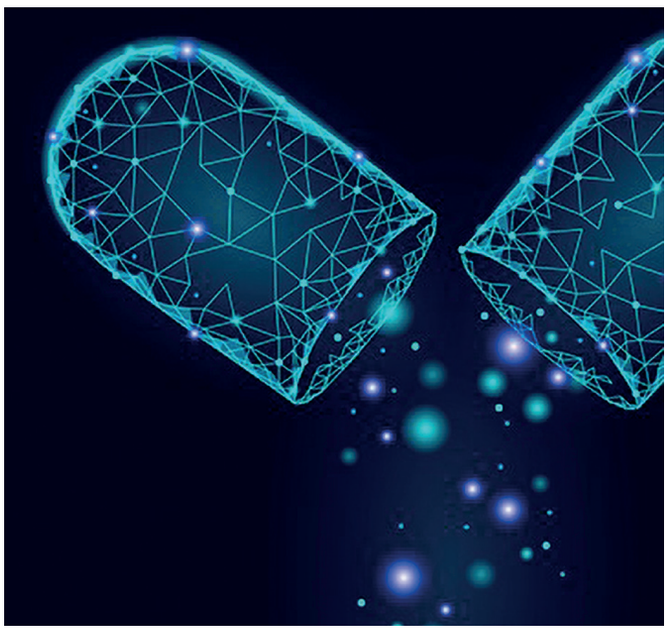

Figure 5: Stylised image of a nanoparticle releasing chemicals

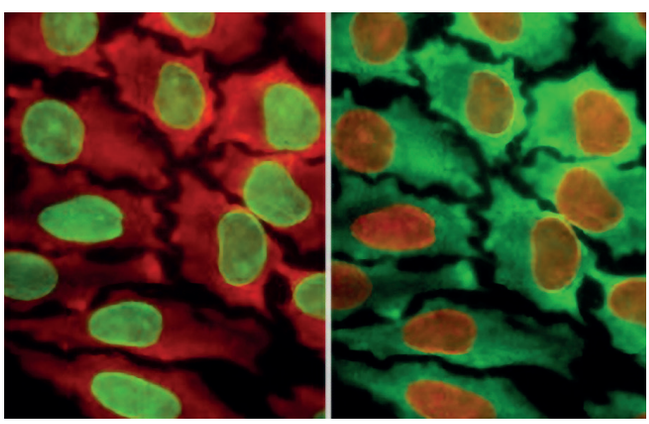

Figure 6: Cell samples stained with quantum dots

effective treatments for cancer and therefore perpetuate the optimisation of cancer therapies.

Nanocapsules are a drug delivery system consisting of a core containing a dissolved drug with a polymeric membrane surrounding it (Figure 4). A polymeric membrane is an organic membrane which can be manipulated by scientists to suit its intended function. In oncology, scientists manipulate the polymeric membrane of nanocapsules to exploit the intensified permeability and extended possession of substances unique to cancer cells. Similar to gold nanoparticles, nanocapsules localise the treatment of cancer; however, instead of acting as the treatment itself, it can deliver the drug to the tumour. Nanocapsules, by the principles of their function, are influenced by an understanding of circulation and unique biochemistry of cancer cells. Therefore, without knowledge in the field of human biology and oncology, the use of nanocapsules in cancer treatment would be limited. Furthermore, the application of nanocapsules to treat cancer reduces the burden on the healthcare system. With approximately 17 million people being diagnosed with cancer in 2018 and a predicted rise to 27.5 million by 2040, healthcare systems in all countries are being pressured to upscale to meet demands. Through the application of nanocapsules, healthcare facilities can treat patients within a shorter time frame and in regard to ethical considerations, reduce patient suffering due to prolonged waiting times. Moreover, shorter therapies for cancer allow for more resources to be devoted towards other illnesses which require more attention from the healthcare system, therefore saving more lives.

Quantum dots are unique nanoparticles that, as a result of their size and structure, will fluoresce when exposed to light (Figure 6). This characteristic, in addition to their ability to recognise and bind with various cancer-specific proteins makes quantum dot cancer screening more accurate in comparison to older methods of treatment. Additionally, quantum dots which emit near infrared wavelengths of light can also be used to identify tumours through a treatment called Sentinel Lymph-node Mapping (SLM). SLM is the process in which the initial lymph nodes affected with cancer are identified via insertion of dye and/or radioactive substances. Radioactive or stained lymph nodes (with quantum dots present) are then examined to confirm if cancer cells are present. Cancers can therefore be diagnosed and treated earlier, reducing further progression and metastases. Although quantum dots are effective diagnostic tools, there are still various side effects yet to be fully explored when they are exposed to the human body. Quantum dots are mainly composed of various metals, which raises concerns for the potential release of cadmium ions which are harmful to the human body. Although in the short term, the stability of the polymer coating would restrict the release of cadmium ions, the long-term effects are largely unknown and therefore it would be unethical to release the product commercially at this stage. This informs public debate on whether the new technologies, which would be beneficial

to people who are currently receiving treatments, should be released in spite of potential ambiguity in side effects.

Despite the clear benefits of nanomaterials as cancer treatments, it is important to assess their interactions with human and biological systems. The application of gold nanoparticles, and modernised drug delivery systems such as nanocapsules and quantum dots, have provided opportunities for more effective cancer treatments which reduce the suffering that cancer and its associated therapies involve, as well as the associated economic impacts. However, due to the potential side effects, acceptance for public usage is under scrutiny. Ultimately, nanomaterials show promise in the amelioration of oncology and entertains the notion that a global leading cause of death could be eliminated; but due to a lack of understanding in their adverse effects more research must be committed to materialise their benefits.

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Andre Geim is the only person to win both a Nobel and Ig Nobel Prize, the latter of which he won for levitating a frog with magnets.

Photo by David Clode

Is Formula 1 on the Right Track?

Words by Saverio Blefari

Chemistry

The most expensive travelling circus in the world has traditionally been using combustion engines and fuels; but by trying to squeeze every ounce of horsepower out of the engine there comes a cost. The governing body, the Fédération Internationale de l'Automobile (FIA) are taking sustainable decisions on board but are they enough? The current ruling states that all entered teams must use a fuel blend containing at least 5.75% of biofuel and by 2022 there must be a 10% ethanol blend, named E10. This must be made of food waste or other biomass instead of specially grown crops for fuel. On the surface it appears as though they are doing a good job of becoming environmentally friendly, but the United Kingdom will outlaw all car combustion engines by 2035. Other countries are also following suit. Formula 1 (F1) has been the birthplace of many innovations now used commonly in everyday cars. With the FIA leading the charge many other organisations and companies will certainly follow through.

Let's look at Formula 1's distant brother Formula E. Formula E is a 100% electric motorsport category. The cars look very similar to Formula 1 vehicles (Figure 1) and in an effort to make them sound similar, Formula E cars have had a speaker placed on them that makes combustion-engine noises. This is a good try, but not overly authentic and thus rules out pure electricity as a viable option - we must turn to other solutions.

This leaves us with only one major alternative, biofuels. Biofuel is an alternate fuel source that uses biomass to create energy. Some sources of biomass are agricultural crop residues, algae, wood processing residues and forestry residues. To make biofuels you first need an oil. These range from animal to plant fats. A source of alcohol is also needed and finally a catalyst, which is generally sodium hydroxide or potassium hydroxide. The catalyst is essential because it speeds up the rate of the reaction. The fats are made mostly of triglycerides which are small molecules, consisting of glycerol and fatty acids. The triglycerides react with the alcohol via a transesterification reaction. The alcohol converts the triglycerides into diglycerides, then into monoglycerides. The reaction leaves the glycerol and fatty acid esters which contain the alcohol from the reaction. Since the glycerol and the fatty acid esters have different densities, they separate. The acid esters can be used as biofuels and the glycerol, once purified, utilised in the pharmaceutical and cosmeceutical industries. Biofuels burn much cleaner than traditional fuels with the potential to decrease greenhouse gas emissions by 86%. Biofuels are also completely biodegradable.

One interesting characteristic of biofuels is that they have a boiling point 3 times less than petroleum. This will mean that teams and drivers will need to be innovative. A cooler engine runs at a more optimal rate – less heat is wasted. However, it will be vital for the teams to exploit this as best they can to maximise performance. Benoit Poulet, Formula 1 development manager for Ferrari's technical partner Shell told Autosport: "The interesting aspect of the car performance is similar to when you put an ethanol-based cooling gel on your fingers - you can feel the cooling effect that you get. It will be the same for the engine. It will be able to cool some parts of the power unit and that could be quite beneficial. We are working hard on it." This could mean that the whole cooling design system of the modern Formula 1 cars will need to be changed, which

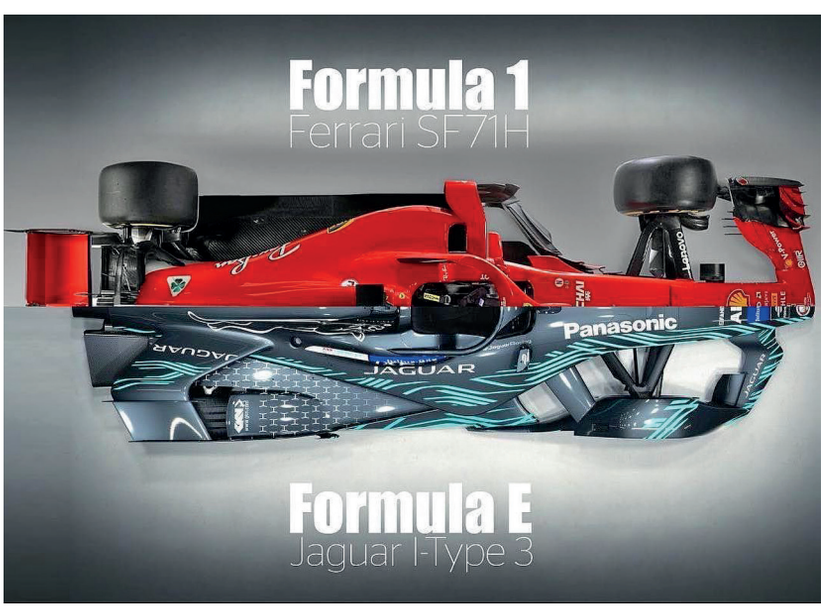

Figure 1

Photo by Hanson Lu

will in turn meddle with the car's intricate array of aerodynamic features. If the fuels used are eco-friendly, then the car could have no restrictions on how much fuel is used in a race since it's clean. "When the next engine does come along, we have a chance to develop a real game-changer, where you're tailoring the fuel and the engine together and that does lead to some much more interesting possibilities. We can show the world that there are alternatives to electric power and there are alternatives to storing electricity in heavy and, I have to say, somewhat dirty batteries," Pat Symonds (one of the most talented and experienced chief technical officers, he worked for many teams including Williams, Benetton and Renault).

Biofuels are a logical step forward in Formula 1 as they offer a renewable source of fuel for race cars without the removal of the roar of combustion engines. Not only are they easier and cheaper to manufacture in bulk they will also present the teams with a technical challenge that will need to be overcome to have a competitive car for the season.

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Many substances can exist in all three states at the same time. The temperature and pressure at which the three phases (solid, liquid and gas) co-exist in thermodynamic equilibrium is known as the Triple Point. For example, the Triple Point of water occurs at 0.01°C and 0.612 pascals.

Photo by Dan-Cristian Pădureț

Maillard Reaction: Its Effect on Nutritional Quality and Protein Ingestibility

Words by Tarun Kamath

Chemistry

The Maillard reaction (MR) affects the nutritional quality of proteins in meals. Originating from France, the MR occurs in almost all forms of cooking and has been specifically utilised by many chefs as part of their culinary practice. This reaction gives the food a distinct taste, which is why it is heavily associated with meats and other protein-rich foods. The reaction occurs in foods such as bread, meats and dairy products that have been cooked, resulting in browning of the surface (see Figure 1). Studies investigating the MR have indicated that this reaction can negatively impact the nutritional value of food, and subsequently the health of the consumer. Ultimately, the impact of MR on society has been influenced by other scientific fields and recommendations regarding the mitigation of MR-related risks.

The MR begins when a sugar reacts with an amine to form a glycosylamine through glycation. Subsequently, 1-amino-1-deoxy-D-fructose is then derived through a process known as the Amadori rearrangement (see Figure 2). Multiple flavour-determining products are formed through a complementary process known as Strecker's degradation. Due to the sustained presence of low heat, the MR will still occur, albeit slowly, at room temperature. It is, however, slowest at low temperatures and low pH levels.

The MR is ubiquitous in many foods; therefore, it can be easily identifiable in foods that are brown in colour such as coffee, meats, and bread. The MR affects the arrangement of amino acids and sugar molecules to form melanoidins, substances that reflect a brown colour in the presence of light and can manipulate flavour. Analysts have determined that the brown colour connotes a lowered nutritional value of the food product. This is due to high levels of furosine (a compound that proves the extent of amino acid damage that occurred due to the MR), which indicates a low amount of lysine in the food product.

As the MR is a non-enzymatic chemical reaction that results in the linkage of amino acids and reduced carbonyl sugars, the presence of heat is required. This can be as simple as leaving proteins exposed at room temperature or subjecting proteins to cooking techniques such as roasting, frying and searing. Heat reduces the nutritional value of food due to a reduction in the number of amino acids and protein availability. A lack of amino acids and proteins can cause deficiency-related illnesses such as fatty liver disease, increased risk of infection due to reduced antibody production, muscle atrophy and other diseases (see Figure 3). Specifically, lysine, an essential amino acid (EAA), decreases dramatically through the MR. The body cannot produce lysine. Therefore, the dietary intake of lysine in appropriate quantities is essential. By having a predominantly MR-rich diet, the consumer may be prone to a range of lysine deficiency-related illnesses such as connective tissue disorder, protein-energy deficiency, and anaemia.

Figure 1: MR induced on chicken to the right.

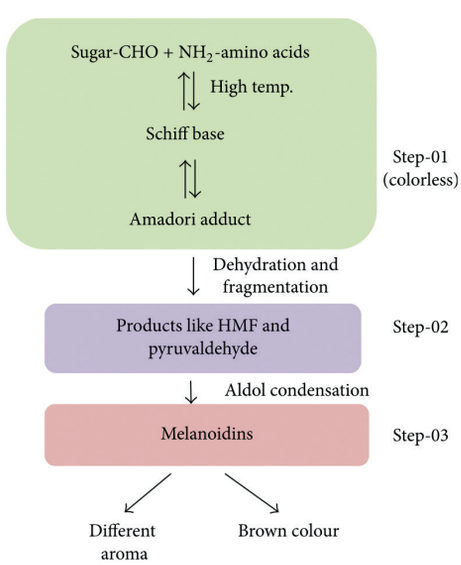

Figure 2: Schematic Representation of the MR.

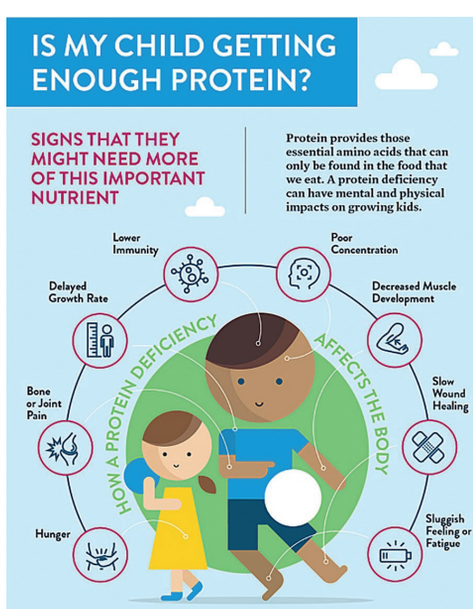

Figure 3: Protein Deficiency Health Risks.

Food storage can have a minimal effect on MR, as food is usually stored in food-safe, temperature-controlled enclosures. This ensures that the proteins will not change during the manufacturing process. High-temperature conditions and inappropriate food packaging can induce the MR on any proteins and sugars present, possibly reducing the nutritional value. Furthermore, heating food has been proven to generate acrylamide and 5-hydroxymethylfurfural (HMF) (see figure 4), which are known carcinogens.

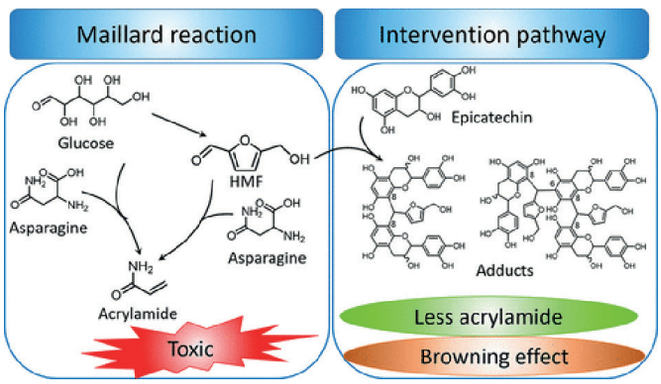

Figure 4: Toxic MR Products and its Intervention Pathway

Advancements in the areas of science regarding the negative nutritional effects of MR have influenced greater public health awareness and advancements in technology. Tanaka's 1977 study proposed that an MR-rich diet could lead to adverse effects on the health of the consumer. This includes a reduction in the digestibility of proteins and the production of toxic substances during the reaction. These detrimental health effects justify that consumers should not have a diet that contains too many foods that are affected by the MR. Additionally, the heat required to produce the MR reduces the protein content of foods, further reducing the nutritional value. By damaging the cell wall and softening the cellulose inside, the fibre content will be lower than that of raw food. Under the *Australian Guide to Healthy Eating (*see Figure 5), fibre is considered to be important for the general Australian diet as it ensures healthy digestion of food. Therefore, the increased prevalence of fibre and other nutritional deficiencies would be harmful to the health of the Australian population as well as government health sector expenditure because of a current dependence on it within the Australian diet.

Similarly, The *American Journal of Clinical Nutrition* also published a study focussing on nutritional health due to an MR-heavy diet. Trials ensured that a control diet – 'white diet' (WD) – and an experimental diet – 'brown diet' (BD) – were regulated to compare amino acid consumption. The WD excluded foods in which the MR occurred during cooking. The BD consisted of foods in which the MR occurred, such as fried, toasted, and breaded meals (see Figure 6). Through the testing of the subjects' faeces and urine, a 6% increase in protein indigestibility was identified, suggesting that BD increases the risk of contracting this disease. Therefore, an MR-rich diet can serve as a public health risk if not consumed in moderation due to its restriction upon essential bodily functions. This risk would affect all members of society who consume MR products.

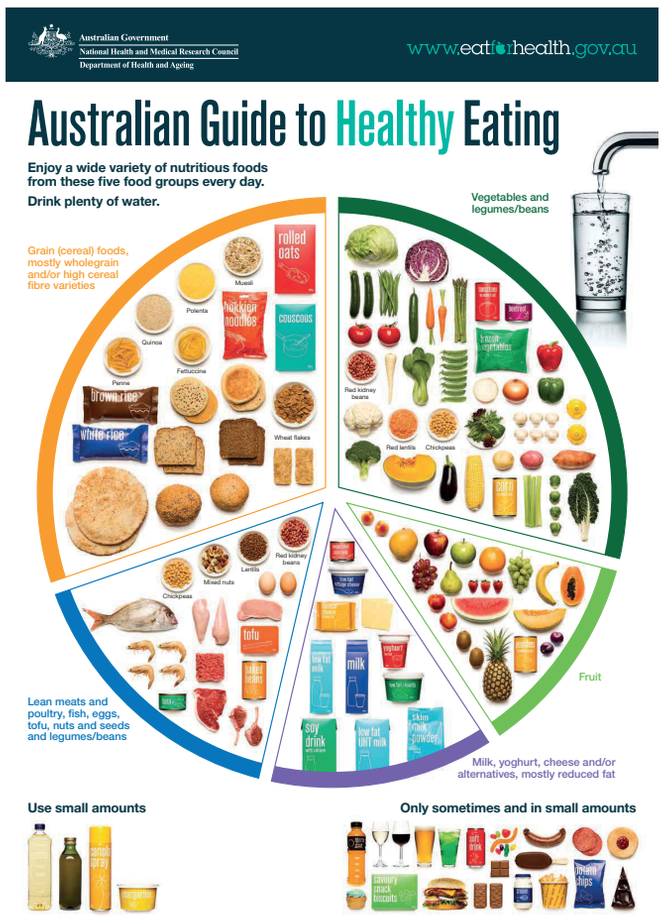

Figure 5: Australian Guide to Healthy Eating

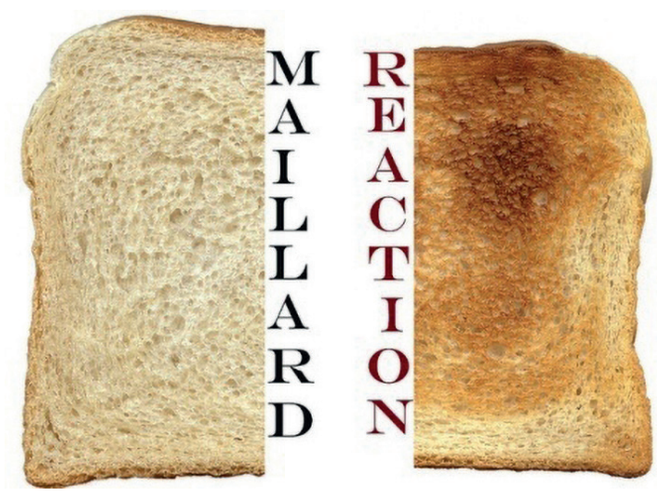

Figure 6: Toast Example of White vs Brown Diets.

Potentially, the MR is dangerous to those who consume foods that contain excessive amounts of MR products. Therefore, the public health risk is presented, influencing the need for the procurement of strategies that mitigate this. New evidence suggests that devastating effects such as protein indigestibility would be harmful to society. As of 2018, Australia was ranked second highest in annual meat consumption per capita (see Figure 7), meaning that a lot of meat is consumed in the diet of an average Australian. Assuming that the meat is cooked, the Maillard reaction has occurred and therefore there is a risk of protein indigestibility and deficiency amongst Australians, a notable public health concern due to its health consequences. This would be detrimental to youth and elderly health as they

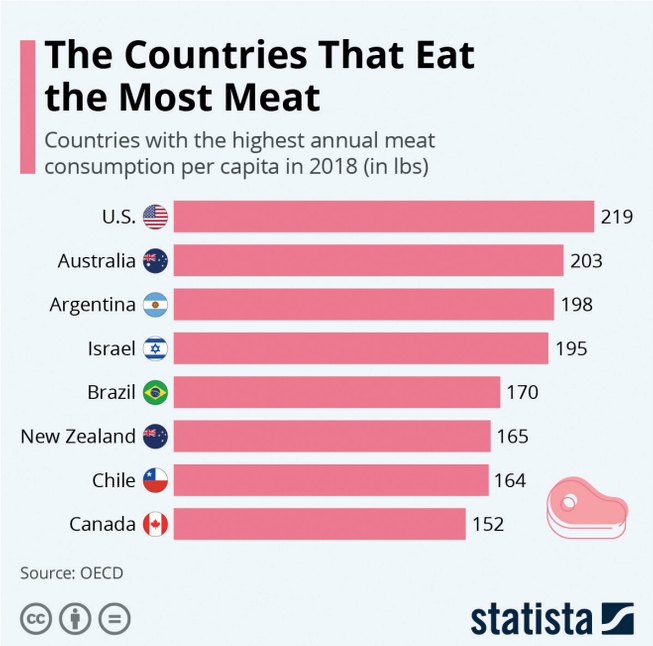

Figure 7: Annual Meat Consumption per capita (in lbs)

Figure 8: Raw Food Pyramid: Proportions and Food Groups

rely heavily on an adequate intake of protein for antibody production and muscle, hair and nail synthesis.

Studies have proven that the MR can induce the formation of acrylamide and 5-hydroxymethylfurfural within the food. Furthermore, Strecker degradation, a process that occurs within MR is proven to form formaldehyde, a dangerous carcinogen. As cancer is an incredibly difficult disease to cure, there is a possibility that it becomes an epidemic, impacting many aspects of society. To combat the harmful products of the MR, scientific research and technology have strongly influenced the mitigation of such negative outcomes. Scientists have concluded that the formation of carcinogens and toxins can be minimised by adding natural and synthetic chemical compounds to certain foods. This is achieved by adding sulphur dioxide, N-acetylcysteine, epicatechin and other agents to certain foods to inhibit α-dicarbonyl formation (see Figure 4), preventing the production of some of the harmful compounds.

The public health crisis arising out of the consumption of MR-rich diets would affect the Australian economy as much more money would need to be allocated to the health sector. Preventative measures in food sources would have to expend resources to ensure that an epidemic of protein indigestibility and deficiency does not occur within the population. Furthermore, if more people are to take time off work to recover from illnesses caused by protein deficiency, productivity will decrease which will negatively impact the economy.

It is difficult to assess whether the health risks of the MR are genuinely acknowledged and widely accepted by the Australian population. Firstly, cultural, social and economic considerations must be recognised. Australians have had access to suitable quality, affordable and diverse meat for centuries. Meat is abundant and accessible all over Australia. Aboriginal communities rely heavily on meat in their diet. Furthermore, Australia's landscape is prime for livestock farming. Due to these factors, it is culturally instilled within Australians to enjoy organising barbeques to socialise and eat meat. Eating meat is lauded within the country and therefore, the health risks associated with MR are faced with apathetic attitudes. To negate the risks of the MR, one may think to adopt *the raw diet* (see Figure 8), a diet predominantly containing foods that are not cooked before consumption. Nutritionists suggest that the raw diet is very strict and does not have many benefits. Although the raw diet may aid in eating fewer calories per volume of food, there is "no proof that eating only raw foods prevents illness". It can be concluded that the information and strategies available to Australians to counteract the detrimental effects of the MR are not viable or currently effective. Therefore, further research must be undertaken.

The MR can be considered as a possible health danger if not moderated in the diet. Due to its ability to reduce protein digestibility and lead to the development of other illnesses, it is a public health concern. However, further research into strategies that will help to mitigate the damaging effects of the Maillard reaction upon the health of the body must be undertaken to guarantee that such effects do not occur.

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Food Fraud and Honey Adulteration

Words by Tom Deakin

Chemistry

Photo by Mariana Ibanez

In September of 2018, allegations were made against Australian honey producer Capilano regarding their supermarket-sold honey products, accusing them of 'adulterating' the honey products so that they can reduce costs. A major point of contention lay within the limitations and reliability of two testing methods used to determine the legitimacy of the honey products in question: C3/C4 testing, and Nuclear Magnetic Resonance (NMR).

The current standardised test for detecting honey adulteration is known as the C4 test and is defined by the Association of Analytical Communities (AOAC) Official Method 998.12 (C4 sugar detection in honey), which analyses the ratio of ^{13}C and ^{12}C isotopes present within collected honey samples. This test is based on the knowledge that bees will primarily collect more nectar and pollen from plants that use C4 photosynthesis instead of C3 photosynthesis. These plants have different isotopic ratios of carbon which affects the isotopic ratio of the produced sugar syrups. Common honey adulterants are produced in C4 plants, such as corn and sugar cane, and can thus be detected through this testing method. However, recent developments have resulted in new adulterants that can circumvent this testing, such as rice syrup and inverted beet syrup, due to their C3 plant origins. This introduction of unanticipated variables has resulted in significant limitations of the currently used testing methods, to a point at which it is unusable in detecting any amount of honey adulteration that uses these newer adulterants.

The proposed alternative application of nuclear magnetic resonance (NMR) spectroscopy would be able to solve this issue, as it relies on completely different principles to the C4 test and is thus able to detect honey fraud that uses both C3 and C4 adulterants. The type of NMR spectroscopy used in analysing honey samples is known as hydrogen-1 (^{1}H) NMR spectroscopy, which applies to organic molecules.

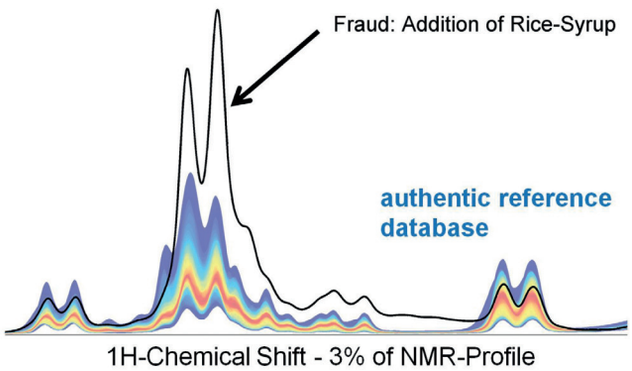

Figure 1: Example spectrum showing honey sample adulterated with rice syrup

A given sample is placed in an NMR machine and exposed to a magnetic field within which the hydrogen atoms resonate, producing data that is represented in the form of an NMR spectrum. The key component for determining honey adulteration is that each molecule will have a unique NMR spectrum due to the unique chemical environments that the hydrogen atoms exist in. Thus, the NMR spectrum produced will be representative of the compounds present within a sample. An example application, shown in Figure 1, is the comparison of a given honey sample to an authentic database reference, which can reveal impurities due to adulteration. The application of NMR spectroscopy in detecting honey adulteration shows the use of scientific knowledge in developing solutions to the problems that arose from the use of C4 testing.

A major motivation for the use of honey adulteration in society occurs because of honey's innately high value due to the amount of effort it required in its production. Increases in global pollution have also been shown to harm honey production, which further increases honey scarcity and thus cost. This economic influence incentivises honey adulteration, as adulteration will increase the profit margin per product through a dilution of the pure honey within the product. This motivation has also resulted in somewhat of an arms race between the two parties, with developed alternative tests, such as liquid chromatography, also being defeated, showcasing further economic influence resulting in morally dubious applications of scientific knowledge to abuse the limitations of current testing. The accessibility of honey adulterants that pass the C4 test through websites such as alibaba.com clearly illustrates the degree to which this form of adulteration is present in the market (Figure 2).

Honey adulteration has impacts beyond consumer fraud. Honey adulteration, through dilution, allows for 'more' honey to be distributed by a company. In isolation, this would only serve to have minimal impact upon the market, but due to the extremely widespread practice of honey adulteration within the industry by companies, the price per unit volume of honey sold has inadvertently been decreased. This leaves farmers who retail their pure honey with much lower profit margins compared to the corporations who choose to export adulterated honey, putting them in a position without sustainable income, showcasing a lack of ethical considerations on part of the companies who choose to participate in this type of food fraud.

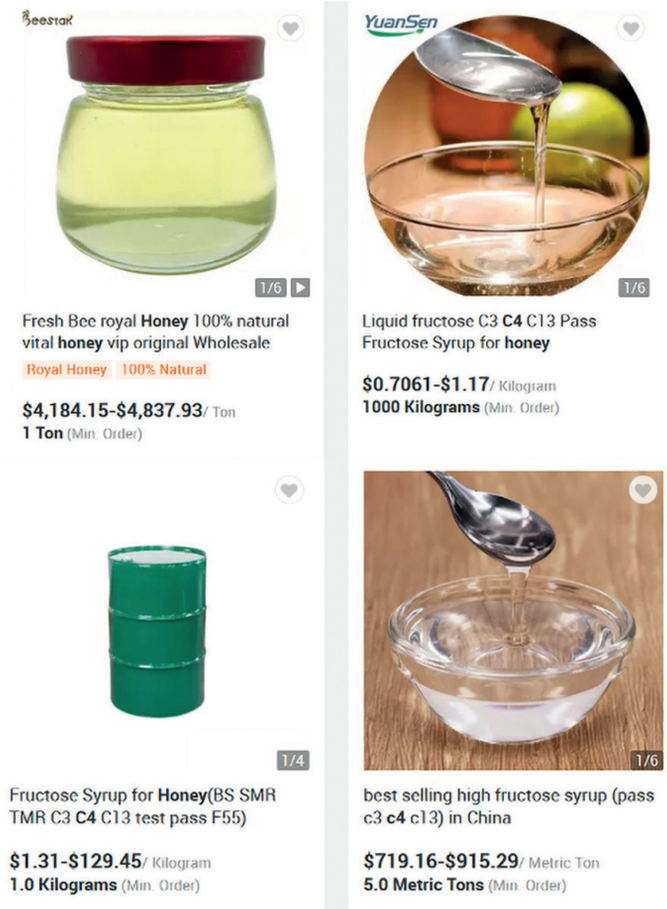

Figure 2: Search results for 'honey c4' on alibaba.com

Furthermore, there is evidence suggesting that honey adulteration has negative impacts on health. A long-term study comparing the effects of adulterated kinds of honey and non-adulterated kinds upon the health of rats over 16 weeks found that the rats that consumed adulterated honeys showed a higher risk of obesity, diabetes, and early mortality. While further research is needed to be done to understand the impact adulteration could have upon human health, this initial testing still showcases clear evidence towards adulterated honey posing health risks. Honey is often associated with certain health benefits, especially as an alternative sweetener, but adulteration only serves to undermine this trust, showing a lack of moral considerations. As a result of greed on behalf of the companies who choose to adulterate honey products, honey adulteration has become a major issue within the farming exports market that has wide-reaching implications upon greater society.

The investigations into the allegation of Capilano's food fraud was never definitively concluded. A media release from the Australian Competition & Consumer Commission (ACCC) states that the ACCC was advised that 'testing is not yet reliable enough to determine whether honey is adulterated or not', and that they 'did not uncover any other evidence that supported the allegation'. This was most likely due to the NMR testing being relatively new at the time of the investigation. However, the investigation also evidenced that 'there is low confidence in the current test method used to detect adulterated honey'. It is not unlikely that Capilano did commit food fraud, but as it is unable to be proven, a legal challenge was never

undertaken. However, the stated findings from the ACCC do provide support to the idea that the current methods used for detecting honey adulteration need to be updated.

With the further research that has been carried out in the years since the 2018 ACCC report on the incident, NMR spectroscopy has been proven to be an effective countermeasure to honey adulteration, being an application of modern scientific knowledge in response to a current issue that carries widespread ethical, economic, and moral implications. However, very little progress has been made in updating current testing methods, with the extent of the problem only growing. The recommendations made to the Department of Agriculture to improve upon their testing methods have not been followed through, despite the worsening of the problem. Until action is taken, the potential for adulteration to become present within Australian markets will only increase, and along with an increase in associated risks to Australians.

The extent of honey adulteration has only grown due to ignorance and stubbornness on part of regulators worldwide. This unwillingness to move on from the outdated C4 test and update the methods used to detect food fraud has resulted in damage to the beekeeping sector as a whole and has brought the potential for an increase in health risks. The application of NMR comes as a solution to the previous limitations found within the C4 testing method, based on social, economic, and ethical influences arising from the prominence of honey adulteration designed to circumvent the current C4 testing methods put in place. The efforts of the scientific community need to be recognised, and the updated testing methods need to be implemented, as this problem will only continue to grow in magnitude until such considerations are made.

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Photo by Beeing

Chaotic Motion and the Double Pendulum

Words by Dylan Holland

Physics

The mathematics of double pendula is a very engaging area since the complexity of the system prohibits predictive models. I had wondered as to the significance of the generalisations made in the construction of kinematic models and decided to explore this. The chaotic pendulum is an example of a system where such generalisations make a large difference to the predicted and actual results. This is fascinating since such examples of chaotic motion exhibit the limitations of a physical model of our universe and expose the inherent issues with the use of such models in predictive roles to set policy and inform decision making in the real world. I have also seen the double pendulum given as an example of university physics and seen several numerical models of a double pendulum and found the unpredictability in its motion fascinating.

A double pendulum is a pendulum where the upper arm is hinged with a separate lower arm attached on the bottom as in Figure 1. Such a pendulum is well known to exhibit chaotic motion.

Chaotic motion is characterised by extreme sensitivity to initial conditions. This results in unpredictable motion that grows exponentially more unpredictable as the system evolves. This implies that, for the double pendulum, two identical pendula dropped from initial conditions which are very close will, over time, become further and further apart.

An example of this could be a simple system described by a bivariate function **f**, with arguments of time, **t**, and the initial position, **x**. Call this a system in 1-D space evolving over time. Let the function f evaluated at time t and x-position **x** be the location of the point, starting at the point in space **(t,f(x,0)** at **t=0**. Let **f** be such that

$$f(x,t) = e^{xt}$$

The general coordinate linking the location and the time of the particle at time t is therefore given by

$$(t,f(x,t)) = (t,e^{xt})$$

If the initial condition is shifted by an arbitrarily small value, **Δx**, then the location of the system becomes

$$f(x+\Delta x,t) = e^{t(x+\Delta x)}$$

By taking the partial derivative with respect to **Δx**, the resultant expression will give a measure of how the location of the system changes as a result of the small perturbation.

$$\frac{\partial}{\partial \Delta x} f(x+\Delta x,t) = \frac{\partial}{\partial \Delta x} e^{xt}\, e^{t\Delta x} = te^{t(x+\Delta x)}$$

Hence, for any initial perturbation to the starting location, , the change of the position of the function with respect to this small perturbation, given by the partial derivative with respect to is strictly greater than zero so long as time is positive. This is clear since time can only be positive. Further, the change as a result of grows exponentially as given by the exponential function in. This implies that as the system develops as time passes, the difference between and grows and that the distance increases exponentially. Let

$$f(x+\Delta x,t) - f(x,t) = g(x,t)$$

Figure 1: Example Double Pendulum

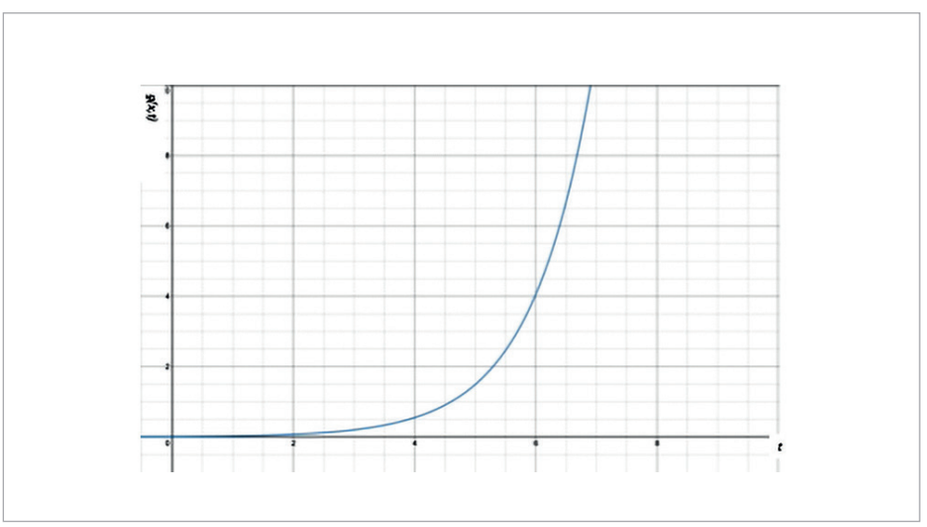

Figure 2: A graph of average separation versus time

The function g gives the difference between position for the original system and the system which was shifted from the original by Δx. The function $g(x,t)$ is plotted in Figure 2 where $g(x,t)$ is the difference between the initial system and a system with an adjacent starting point, differing by only Δx.

An equivalent formulation would be,

$$f(x+\Delta x,t) - f(x,t) = e^{t(x+\Delta x)} - e^{tx}$$

Since Δx is independent of time and the initial conditions, x, it can also be said that, by simplifying and substituting a constant k in for $(e^{\Delta x}-1)$,

$$e^{t(x+\Delta x)} - e^{tx} = e^{t}\,(e^{(x+\Delta x)} - e^{x}) = e^{tx}\,(e^{\Delta x-1}) = g(x,t)ke^{tx}, k \in R$$

This is merely a growing exponential function with respect to t since $t>0$. This is a chaotic system since the difference increases exponentially.

At large angles, the double pendulum exhibits this same behaviour and hence, as the system develops, the distance between the x and y locations of two pendula dropped adjacent to each other with a miniscule difference between initial starting conditions grows exponentially over time.

The evolution of a dynamical system can be approximated in terms of time and a constant called the Lyapunov exponent, λ. This Lyapunov exponent gives a measure of how infinitesimally small perturbations to the initial conditions develop and the rate thereof. The general form of this relation can be given by

$$|\Delta s(t)| = |\Delta s_0 \,|\, e^{\lambda t}$$

For the function Δs governing the evolution of a system—similar in role to the function g—the initial perturbation is given by Δs_0 and the time elapsed is given by t. The units for λ are such that the product in the exponent is unitless. This implies that, since time is measured in seconds, the Lyapunov exponent has units of s^{-1}. The absolute distant between adjacent starting positions, $|\Delta s|$, can therefore be expressed as a function $|\Delta s(t)| = |\Delta s_0 \,|\, e^{\lambda t}$.

If the Lyapunov exponent is positive this implies that the distance between adjacent trials grows over time since for a positive Lyapunov exponent, the system evolves in accordance with the above function and for all $t > 0$, $|\Delta s_0 \,|\, e^{\lambda t} > |\Delta s_0 \,|$. By taking the natural log of both sides, the equation becomes

$$\ln|\Delta s(t)| = \ln|\Delta s_0 \,| + \lambda t$$

From this, we can see a linear function in t with the gradient equal to the Lyapunov exponent and the y-intercept equal to the natural log of the initial perturbation.

This growth however was found to vary over time with the Lyapunov exponent oscillating between positive and negative positions, with an overall average of a positive Lyapunov exponent, implying growth of positional difference over time. This was found to be due to the lower pendulum acting upon the upper in such a way that the system behaves non-chaotically, i.e. as if it has a negative Lyapunov exponent, for that period of time. Hence the expected variation of the distance between adjacent trials should oscillate but have an overall exponential growth of . After a number of oscillations about the rest position, the pendulum loses energy due to friction and hence stops exhibiting chaotic motion. Hence, the number of points selected must be limited to ones before the system has lost sufficient energy to become non-chaotic. The non-chaotic motion exhibited by small angle pendula is caused by the fact that at small angles, the restorative force is approximately opposite to the direction of motion. This is the same principle which allows the simple pendulum approximation to create simple harmonic motion.

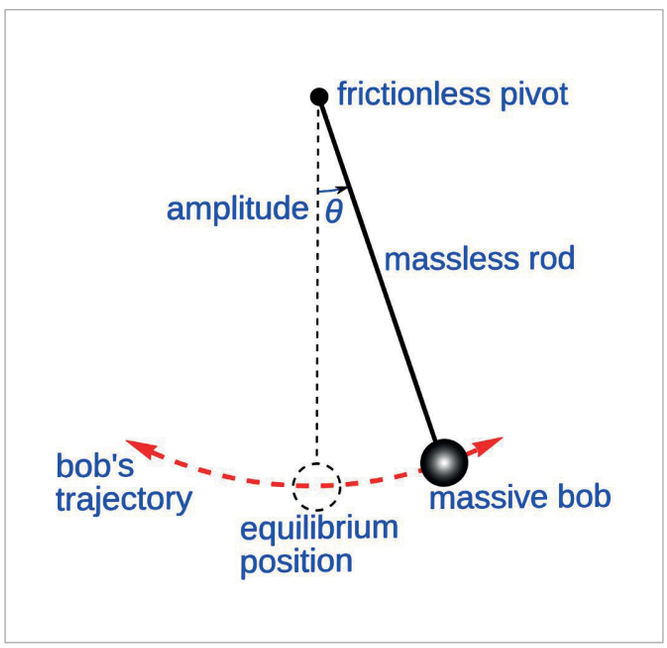

Figure 3 Simple Pendulum

For Figure 3, the force on the bob is equivalent to its weight $\vec{W}$ and proportional to the acceleration due to gravity, $\vec{g}$, and the mass of the bob, m, given by

$$\vec{W} = -m\vec{g}$$

If the system exists in a 2-D vector space, these can be written in component form, using the angle from the vertical θ as,

$$\vec{W} = \begin{pmatrix} w_1 \\ w_2 \end{pmatrix} = -m\,|\vec{g}|\,\begin{pmatrix} \cos\theta \\ \sin\theta \end{pmatrix} = \begin{pmatrix} -m|\vec{g}|\,\cos\theta \\ -m|\vec{g}|\,\sin\theta \end{pmatrix}$$

Since at small angles in radian of θ, $\sin\theta \cong \theta$, for small angles of θ,

$$\vec{W} \cong \begin{pmatrix} -m|\vec{g}|\,\cos\theta \\ -m|\vec{g}| \end{pmatrix}$$

This gives a system which oscillates with a sinusoid function giving the horizontal force. This type of system exhibits simple harmonic motion and is entirely predictable.

This same principle goes some way as to explaining why small angles do not exhibit chaotic motion as it must contain sufficient energy for the system to exhibit chaotic motion.

Much like the bivariate function $\boldsymbol{f}$ approximating the development of a system, a chaotic system with a small perturbation will rapidly diverge and quickly—within an oscillation—become completely unpredictable and nondeterministic. This can clearly be seen in Figure 1, which graphs the time against the absolute scalar displacement between two nearly equal starting locations, $|\Delta s|$, for a chaotic double pendulum as in Figure 1. The slope of the trend line gives an approximation for the global Lyapunov exponent (as shown in Figure 4 below).

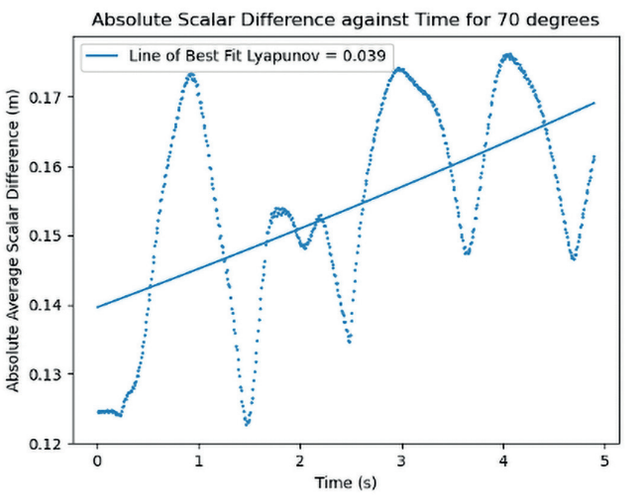

Figure 4: Illustration of Absolute Scalar Difference against Time

Overall, chaotic motion is motion which is non-deterministic for any initial starting position which is not known to infinite precision. It is characterised by sensitivity to initial conditions such that the distance between adjacent starting positions grows in an exponential manner and very rapidly diverges.

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Considering the average human hand weighs 0.4kg and has a velocity of 11mls when slapping, it would take approximately 23,034 slaps to cook a chicken.

Photo by Anshu A

Nuclear Medicine – Radiotracer Cobalt-60

Words by Hemanth Condapatti-Ravi

Physics

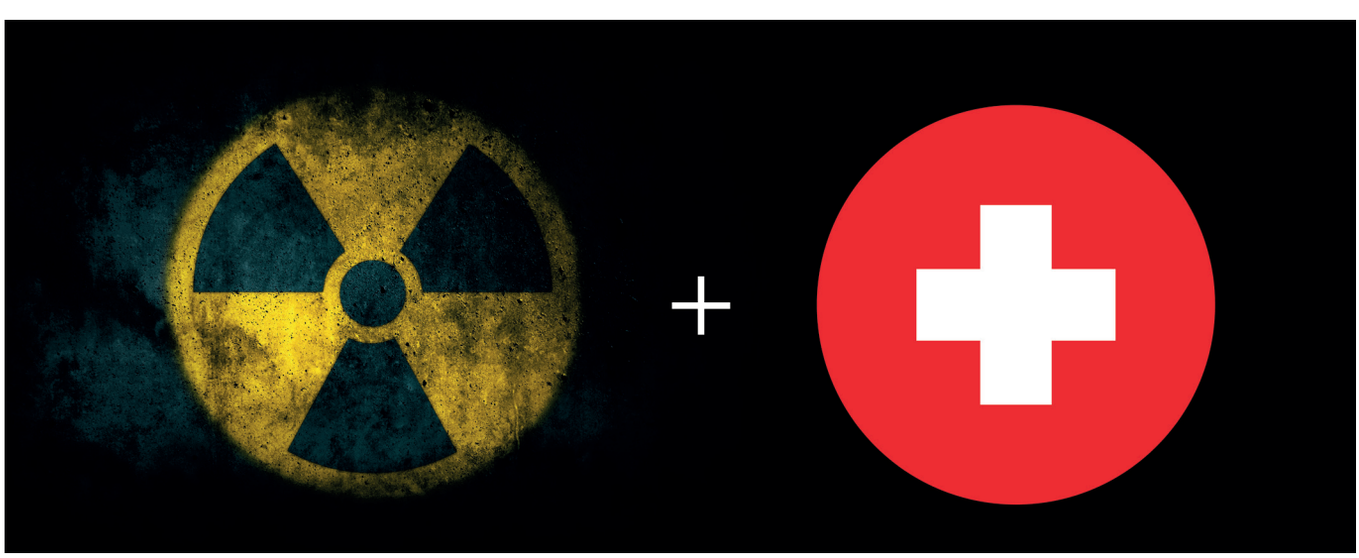
Radioisotopes have been used extensively from the time of their discovery to study physical, chemical and biological processes. There are many useful applications of radioisotopes, however, the application with the biggest impact from the use of radiotracers is in medicine, where radionucleotides have been incorporated in biologically active molecules and used to both diagnose and treat a wide variety of diseases. The advances in imaging technology in recent years has had a profound impact on the use of radionucleotides, which have helped in the diagnosis and treatment of a range of medical conditions. One of the most commonly used radiotracers for this purpose is Cobalt-60, mainly used in cancer treatment. This report describes the background of this radiotracer, as well as providing information regarding the various influences on the development of this technology and its applications and limitations.

A radioisotope is any form of the same chemical element with a different mass as of the different number of neutrons. As a result, the nucleus of the atom becomes unstable and dissipates energy by radiating alpha, beta and gamma rays. These rays are powerful enough to destroy living cells, in particular cells in tumours. Alpha radiation results in the formation of an alpha particle as it decays, which are heavier in comparison to beta and gamma particles. This radiation has a high ionising capability, but due to its heavier mass, it also has poor penetrating ability. In contrast, beta radiation consists of a smaller particle which moves faster than alpha particles, thus resulting in its low ionising capability but an increased penetrating ability. Gamma radiation has no mass and carries no charge; thus, it can travel at the speed of light. Since these rays infrequently interact with matter, they have a poor ionising ability. Gamma rays are said to be able travel an almost unlimited distance in air and even a few centimetres into lead or concrete.

Cobalt-60 is a radioisotope was first discovered by George Brandt in 1735. Cobalt-60 is created through a process called activation, which occurs in a nuclear reactor. In the reactor, naturally occurring Cobalt-59, a stable isotope of Cobalt, is bombarded with an excess of neutrons at high speed, which can be absorbed by the nucleus and thus increases the mass number to 60. Thus, the nucleus within the atom becomes unstable, enabling the emission of radiation to occur. Usually, this isotope dissipates energy through gamma rays, and occasionally via alpha and beta rays. Since Cobalt-60 usually decays through gamma radiation, it can be utilised with cancer treatment. By ingesting the isotope or using teletherapy machines, the beam of gamma rays can be directed into the patient's body in order to locate and kill the tumour tissue. Below is a chemical equation showing the absorption of the neutron and then the decay of Cobalt-60 into gamma rays:

$$^{59}_{27}\mathrm{Co} + \mathrm{n} \rightarrow {}^{60}_{27}\mathrm{Co} \rightarrow {}^{60}_{28}\mathrm{Ni} + \mathrm{e}^{-} + \bar{\nu}_{\mathrm{e}} + \text{gamma rays.}$$

The acceptance and use of radiotracers in nuclear medicine can be influenced by social, economic and ethical considerations. The economic factors, including the cost of the Cobalt-60 treatment should be taken into account. According to *The Next Big Future*, a gram of Cobalt-60 costs approximately $280 USD, which would cost thousands of dollars in order to fully treat a patient. As a result, it is a rather expensive



treatment, which becomes a major setback in its application. Although the treatment has been thoroughly tested since the 1950s, there are some risks involved. Since Cobalt-60 decays through gamma radiation, over-exposure to the isotope can cause skin burns, acute radiation sickness, or even death. When undergoing Cobalt-60 treatment involving its ingestion, it is usually excreted in the faeces, but a small amount can be absorbed by the liver, kidneys and bones. Although it is a minimal amount, Cobalt-60 has a long half-life of 5.3 years, which means that it is possible to form further cancer due to the body's exposure to the gamma radiation.

The use of radioisotopes such as Cobalt-60 may have beneficial or unexpected consequences. A beneficial outcome to the use of Cobalt-60 treatments is how over 35 million cancer patients worldwide have benefitted from this. Dr Jerry Battista of London's Regional Cancer Program states "*The development of Cobalt-60 radiation therapy opened a window into the human body and for the very first time in history, we were able to treat deep-seated tumours without hurting the skin,"* which shows how the development of the Cobalt-60 treatment stimulated the use of other radioisotopes in cancer treatment. Moreover, it can be stated that the treatment of cancer through the use of Cobalt-60 is not always effective, and can result in adverse effects. Occasionally the treatment may fail entirely. If this were to occur, it could result in possible death. This is supported by how most radioisotopes, including Cobalt-60, can only treat common cancers, such as breast cancer and bowel cancer, and only has a 40% overall success rate.

Although Cobalt-60 has the ability to cure cancer affected individuals, there are still many improvements that can be made to the technology in order to advance the quality of the treatment. Some of these include making the treatment safer, more reliable and even more effective. However, in recent years, scientific discoveries in other fields have shown the possibility of curing cancer and other diseases through other means instead of radioisotopes. This makes one question if radioisotopes such as Cobalt-60 has a sustainable future in the treatments of cancer?

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Fleas can jump 130x times higher than their actual height. In human terms, this is equal to a 6ft person jumping 780ft.

Photo by Cam Adams

A New World for Australia's Energy Sector

Words by Max Thomas

Physics

The world is currently witnessing the largest transformation of our electricity production since the Industrial Revolution. Movements working towards more environmentally sustainable energy sources have seen both a rapid development in technology and the abolition of previous energy sources. However, a resistance towards a transition towards green energy has resulted in 75% of Australia's electricity generation still being sourced from coal. With no recent governmental embracement of new energy options, it is both worth analysing recent technological developments in the sector and Australia's long-term economic viability as a major electricity exporter.

Nuclear power, although being fairly popular in Europe and the United States, has faced large opposition in Australia for over fifty years. This is both due to environmental concerns over the associated toxic waste and the strong link between nuclear power and the development of nuclear weapons. Moreover, Australia's abundance of coal in the past meant that nuclear power development was never really entirely necessary. That said, with climate change activism pressuring a transition away from Australia's strong dependence on coal, a reconsideration of nuclear power has emerged. Nuclear fission reactors produce electricity by harvesting the energy produced during the nuclear fission of the Uranium-235 isotope. This occurs due to nuclear fission releasing a huge amount of heat in the process of the nucleus of an atom splitting into two or sometimes more nuclei. This heat is then captured and transforms water in reactors into steam which then spins huge generators which produce electricity. The issue with current nuclear power technology is the significant amounts of toxic waste that persist when the radioactive material is no longer efficient in producing electricity. Incidents such as the Chernobyl and Fukushima disasters have further prompted public opposition to nuclear energy more broadly.

However, recent technological developments have boosted confidence in a new type of nuclear power: nuclear fusion. Although only in development stages currently, and not yet effective in harvesting electricity, several governments have invested vast amounts of money into the development of nuclear fusion technology. It differs significantly from the current nuclear fission technology, as it aims to recreate the fusion reactions that power the sun to create a far more efficient energy source with no toxic waste and connection to nuclear weapon proliferation. The process works by using deuterium or tritium gas (heavier isotopes of hydrogen) in a sealed reactor, heating it to over 100 million degrees Celsius until it forms a plasma-like state, and harvesting the energy that is released when the atoms bond to form helium (Figure 1).

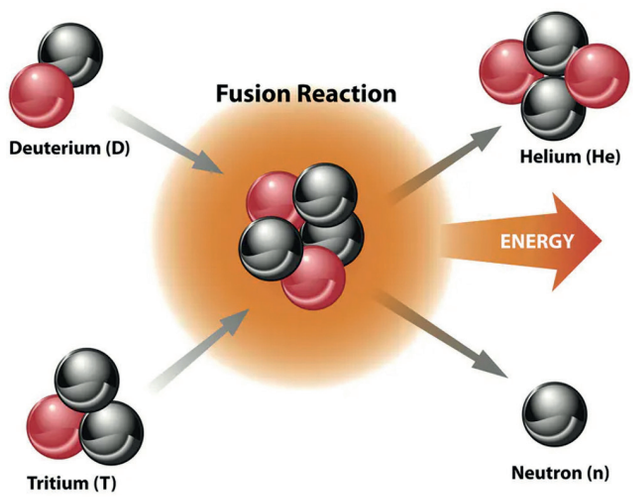

Figure 1: Fusion reaction used in the release of energy

This process, apart from the creation of the reactors, has a net-zero carbon footprint and does not have the toxic waste and nuclear weapon proliferation issues faced by nuclear fission reactors. As this process aims to directly recreate the reactions that drive the sun, nuclear fusion power has been dubbed as a "sun in a box". The development of this technology has been partly funded by the Australian government and is a major research focus at the University of NSW. It is unlikely that this will be a viable electricity source for at least ten years, although the current trajectory suggests that we are certainly nearing this possibility.

Renewable forms of energy, such as solar power are also worth investigating. With the vast amount of land particularly in central Australia, numerous groups have highlighted the potential to construct solar farms to meet our domestic demand and open up export markets for electricity. Solar technology in particular has also been constantly improving since its creation in 1839. Developments in nanotechnology over the past 15 years have allowed the silicon crystals which comprise solar cells to become thinner, which increases efficiency. Perovskite, a mineral that is mostly composed of calcium titanate, is also being used to create very thin films which are very effective for the absorption of solar radiation. This continuous development of solar technology has seen a 7% efficiency increase in harvesting electricity over the past 10 years, and this is only likely to increase into the future.

Not only is this technology becoming more efficient but has the capacity to produce over 100,000 jobs in the next decade, whilst lowering greenhouse emissions. This new electricity network could also have the capacity to export electricity to Asia via underwater cables that lay on the ocean floor. This has been proposed by an Australian company SunCable, which have detailed plans to build a 20-billion-dollar solar farm in the Northern Territory to export electricity directly to Singapore via a direct high voltage seafloor cable. Although Australia is only responsible for about 1.4% of global greenhouse gas emissions, our potential as a major exporter of renewables is becoming increasingly likely with the development of these forms of energy production. This would make Australia a 'sub-zero' greenhouse gas emitter, by way of reducing the dependence on coal and gas that other countries currently have. That said, it will require a huge amount of investment from governments and the private sector if the goal is to be properly realised. Potential negative impacts on our economy also need to be considered.

Ultimately, Australia's energy sector is going to look very different in the future. The rapid development in technologies such as nuclear fusion, improved solar efficiency and underwater cables which have the potential to make Australia a renewable energy superpower collectively mean that we will likely become far less dependent on unsustainable resources such as coal and gas. That said, it is going to require significant investment into research and construction projects from the Australian government, something that could indeed be a very difficult task given their current stance on electricity production.

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Photo by Matthew Henry

Engineering The Galaxy - The Dyson Sphere and Unlimited Power

Words by Regan Nelson

Physics

The Dyson sphere is an incredibly intricate, yet simple project proposed by Freeman Dyson (1923–2020), a man before his time. Freeman was a legendary theoretical physicist.

He was born in England and served in the 2nd World War where he designed formations for Bomber Squadrons. He studied at Trinity College and attained a BA in Mathematics. In 1951 he joined the Faculty at Cornell despite not having a doctorate, which he never acquired.

Freeman Dyson did not subscribe to education accolades and approached mathematics and science from a different perspective. While he won many scientific awards, he never achieved a Nobel prize and had remarked in 2009, "I think it's almost true without exception if you want to win a Nobel Prize, you should have a long attention span, get hold of some deep and important problem and stay with it for ten years. That wasn't my style."

In 1960, Dyson wrote a short paper for Science, titled "Search for Artificial Stellar Sources of Infrared Radiation". His idea was to use an extensive array of solar panels or mirrors around the Sun to produce infinite energy for civilisation by harnessing the solar radiation output and redirecting it towards the Earth.

Energy and how we consume it is the defining limit on humanity and is one way that human history is defined. In the beginning, we primarily used the kinetic energy of our muscles to achieve our goals; then, we harnessed the energy of fire and cooked our food and used it to keep warm. Next, we industrialised the world by burning coal and oil to produce electricity which powered and developed new approaches to our existence. Then we discovered splitting the atom and harnessed nuclear energy for good and evil.

We are now at a turning point of finding new 'green solutions' to the world's energy needs. At every step of this ladder, humanity has increased its energy output drastically. Figure 1 shows that since 1820 our appetite for energy has been growing at an ever-increasing rate. Now, as humanity looks to expand exploration further into the solar system our energy demands will increase further. Space exploration will require an amount of energy the likes of when we have never experienced.

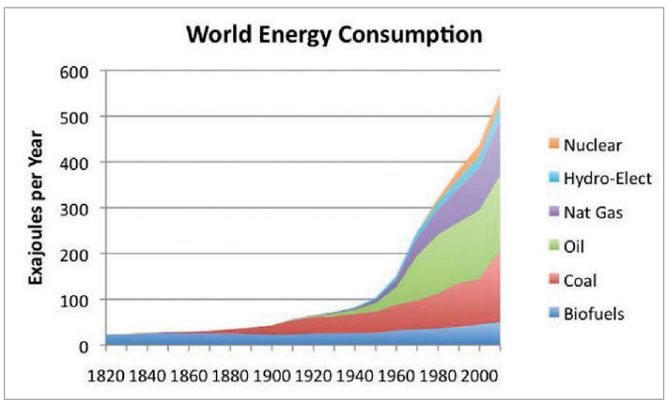

Figure 1: World Energy Consumption by Source

If humanity were to use all the fossil fuels and uranium on Earth to launch as much mass as possible into space, we would be able to only launch roughly the mass of Mount Everest into space. The Dyson Sphere would be able to replace the fossil fuel industry thousands of times over.

Currently, humanity uses roughly 580 million terajoules or 580 trillion joules of power every year. However, according to Dyson Spheres and the New Age of Energy, "By using a Dyson sphere, we would have access to a colossal 400 septillion joules of solar energy. That is a trillion times more power than what the entire Earth consumes today."

By using a Dyson Sphere, humanity would never have to worry about having the energy to power society. However, due to the sheer scale of this project, we almost need the power output of a Dyson sphere to build a Dyson Sphere.

Some ideas for a Dyson sphere propose a solid shell around the Sun as written by TJ Wright from Harvard University in 2020. However, this could be incredibly disastrous as not only would it block light from reaching Earth, but it would also be highly susceptible to a catastrophic failure that would cause the sphere to fall into the Sun. Instead, a much more efficient and safe proposal is a 'Dyson Swarm'. A Dyson Swarm is a massive swarm of mirror panels deployed around the Sun to redirect and concentrate light, as in Figure 2.

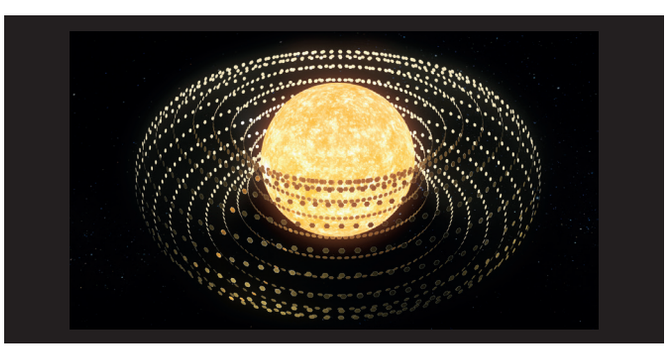

Figure 2: Dyson Swarm

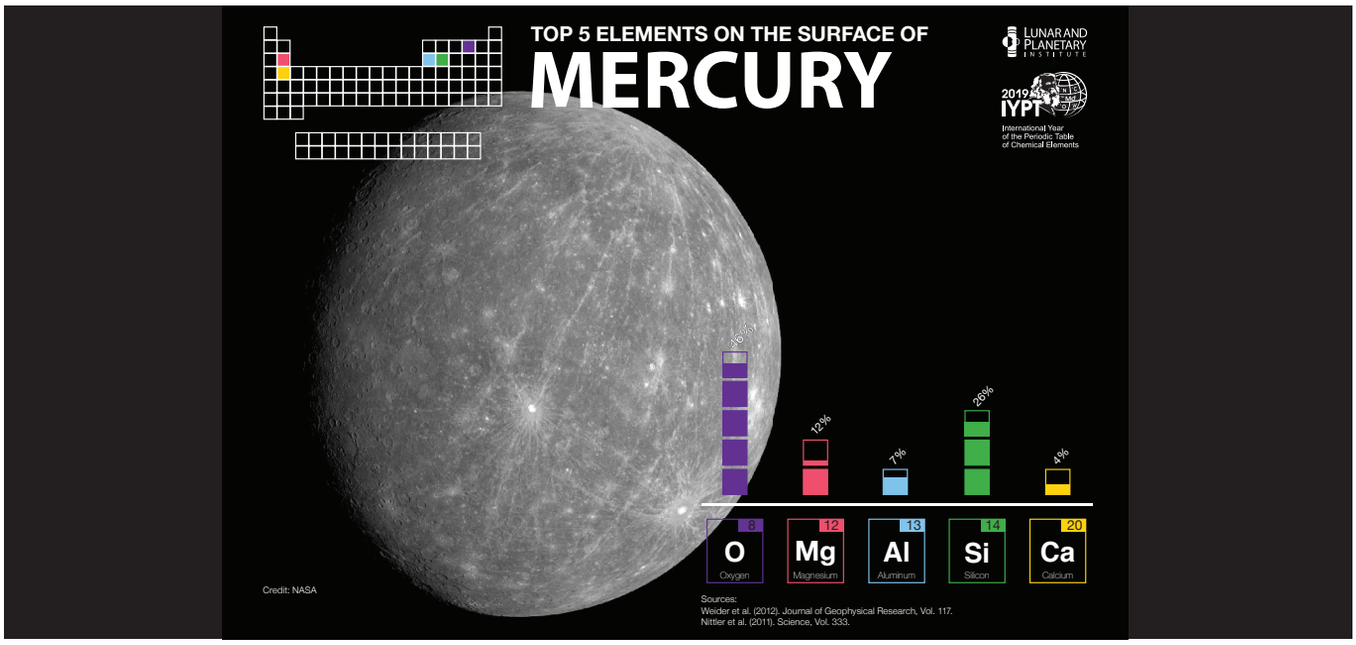

Figure 3: Top 5 Elements on Mercury

The intent would be to collect and harness energy from central nodes before being sent back to Earth and potentially around the solar system to aid in colonising the energy-poor Mars. The panels would not need to be complicated, just a simple one-kilometre sheet of aluminium a few millimetres thick which could be mined and constructed from nearby Mercury by robots. Figure 3 below shows the top 5 elements on the surface of Mercury. These would be used like the mirrors of a solar collector back on Earth, making the whole process much cheaper and more efficient.

Based on this size, it would take roughly thirty quadrillion panels to surround the whole Sun at height of 5 million kilometres from its surface to keep the aluminium panels from melting (aluminium has a melting point of 660°C). This is based on the temperature of Mercury at 450-degrees Celsius, 46 million kilometres from the Sun. In addition, by using the Parker Solar Probe NASA has concluded that at 5 million kilometres from the Sun the temperature would be 120 degrees Celsius. This would make the Aluminium panels easily capable of surviving at that distance.

It is inspirational to imagine what could be achieved in the future if humanity decides to work together and combine the scientific resources we have available now. Could we develop the systems to deliver robots to Mercury that could mine the planet, build more robots and create sophisticated panels for harnessing huge amounts of usable energy to support humanities future plans and desire to colonise Mars or seek out other solar systems? What do you think?

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What's next for the International Space Station?

Words by Samarbir Singh

Physics

Buckle yourself up! We are going on a journey through time and space to explore the future of the International Space Station (ISS). There have been a number of predictions regarding the oncoming changes to the space station by 2024, which has survived for two decades thus far. The theme of these changes is to generate the safest and most developed technology, so that our future can be clearer than ever before. We are aiming to move forward together by introducing recommended technology and modifications in our current equipment to shape the future in the form of a new gateway. These modifications will not be limited to recreate existing machinery, but also to evolve the present into the future through the latest innovation - the 'Lunar Gateway'.

Figure 1 below shows a digital representation of the planned Lunar Gateway. The principal purpose behind its construction is to establish an orbital outpost for the moon. However, it will also have additional pragmatic benefits.

The Gateway will function as a critical component of NASA's Artemis program. NASA expects not only to propel crewed missions into various abodes in outer space, but also to send multiple spacecraft for the purposes of deep space exploration, alongside different space apparatus and human landing systems that will eventually lead space explorers to the moon. Moreover, the Gateway will also assist in acquiring new experiences for astronauts and operators which can eventually be used to send humans to Mars in the future.

The introduction of the Lunar Orbital Platform-Gateway is vital for space travellers to increase time spent on the Lunar Surface. NASA aims for space travellers to spend up to two months on the moon. The excess amount of time spent on the moon will allow for more samples, data and information to be collected so we can learn more about the Lunar Surface. The Lunar Gateway will grant for this goal to be achieved as it will serve as a docking point, permitting no shortages in fuel, or other resources. It can also serve as an emergency location in case of any accidents.

The Gateway will also serve as an alternative if the current ISS malfunctions. After 20 long years, the ISS cannot continue any further as it has faced many impairments over the years, in particular a constant air leak and breakdown of the oxygen generator - a crucial life support component. Although it has been repaired, other downfalls of the ISS suggest that its time is up. Along with the ageing current technology in the ISS, the facilities and other resources have also become weathered over time. These issues have led NASA to conclude that it is time to shape the idea of the Lunar Gateway into a reality.

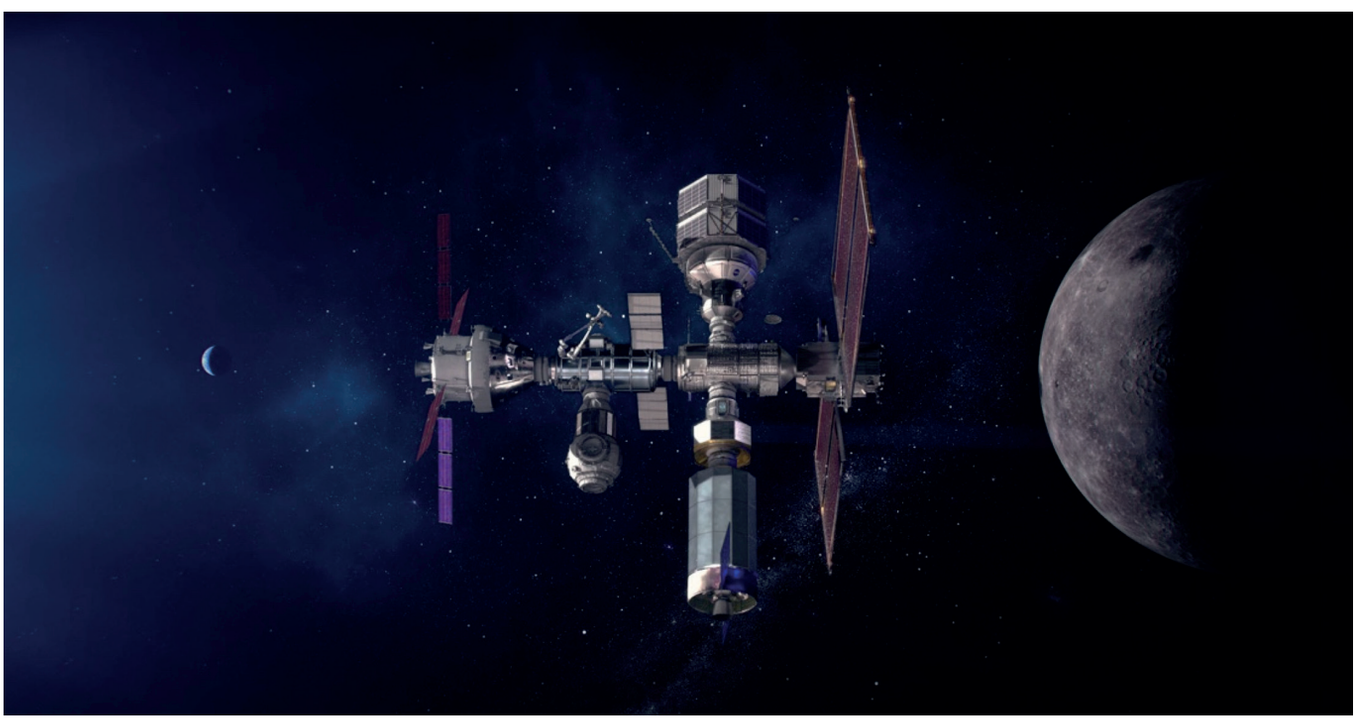

Figure 1: The Lunar Gateway when its construction is completed.

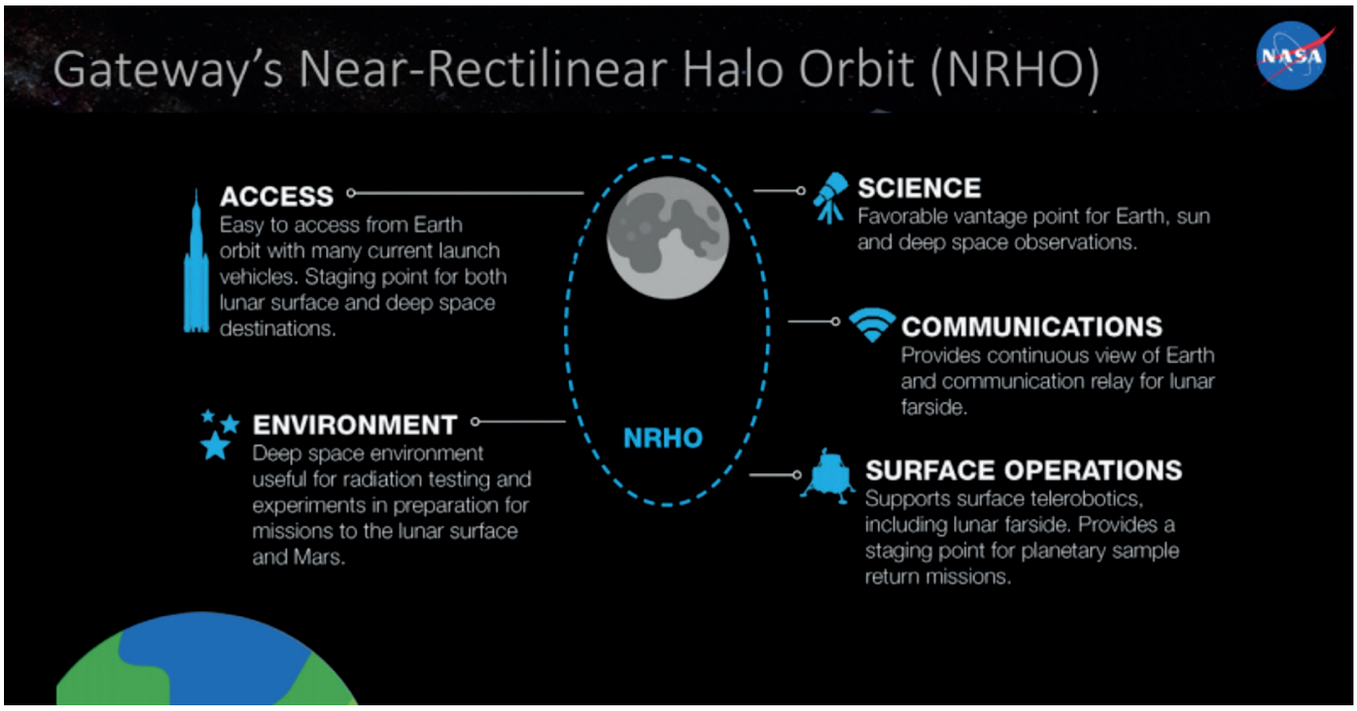

Figure 2: A map of the Lunar Gateway orbit around the moon.

The Gateway will fly between 20,000-76,000 kilometres away from the Moon, following an egg-shaped orbit. This orbit type will allow astronauts to choose reasonable spots to land. The Gateway's orbit would be able to adjust to reach the designated landing spots, serving as a docking point between the Moon and Earth.

Traditionally, the ISS followed an orbit around the Earth, but the Lunar Gateway will orbit the moon, shown in Figure 2. This is because the lunar orbit is better for studying the moon. For instance, the lunar orbit will permit the study of the far side of the moon whereas the usual earth orbit doesn't allow this to be studied. Furthermore, the traditional earth orbit requires more energy or fuel and lots of station-keeping for it to stay there (in orbit of the Earth). Any occurrence of a malfunction leaves it too unstable to maintain its position, leading it to drift away entirely unless very powerful thrusters are used. However, it won't be a significant problem in the lunar orbit. Hence, the orbit is a part of many diverse changes that the Gateway will have from the ISS.

The new Lunar Gateway would be 1/6 of the size of the original International Space Station. The structure of the gateway will consist of five modules or interlocking parts. Approximately one or two of these will hold space explorers, one will serve as solar electric power, and the others will serve as airlocks for spacewalkers and a landing area for spacecraft.

This configuration concept of the Lunar Gateway is split into different parts, created by different companies:

1. Power and Propulsion Element:

This part is responsible for the power, communications, altitude control and transfer capabilities of the Gateway. Created by: NASA.

2. ESPIRIT:

This is the airlock, supplementary propellent storeroom with refuelling, and superior lunar satellites capabilities. Created by: European Space Agency.

3. U.S. Utilisation Module:

A small, compelled capacity for extra habitation. Created by: National Aeronautical Space Agency (NASA)

4-5. Habitation Modules (two parts):

Pressurised dimensions with conservational regulators and life support, fire detection and subdual, water loading and dispersal. Created by: European Space Agency and Japan Aerospace Exploration Agency.

6. Airlock:

Permits potential spacewalks to accommodate docking components. Created by: Roscosmos State Corporation for Space Activities.

7. Logistics and Utilisation:

Cargo distributions of food and equipment. Components may double for supplementary operation volume. Created by: National Aeronautical Space Agency (NASA) and Japan Aerospace Exploration Agency.

8. Robotic Arm:

Automated arm to dock and examine vehicles and install freights. Created by: Canada Space Agency.

9. Sample Return Vehicle:

A robotic vehicle proficient of transporting small samples from the moon to the Gateway. Created by: To Be Confirmed (TBC).

The Lunar Gateway heavily relies on several vast space corporations to support its creation. NASA expects that approximately $331.8 million dollars will be spent for its making and missioning. This money covers the costs of transport of the Lunar Gateway into the moon's orbit as well.

The Lunar Gateway has a life expectancy of at least 15 years. This time frame will include multiple renovations and changes in databases and technology. The current ISS has lasted for 20 years with many renovations which included:

- Upgrade in pressurised volume, i.e. the same as a Boeing 747 jetliner.

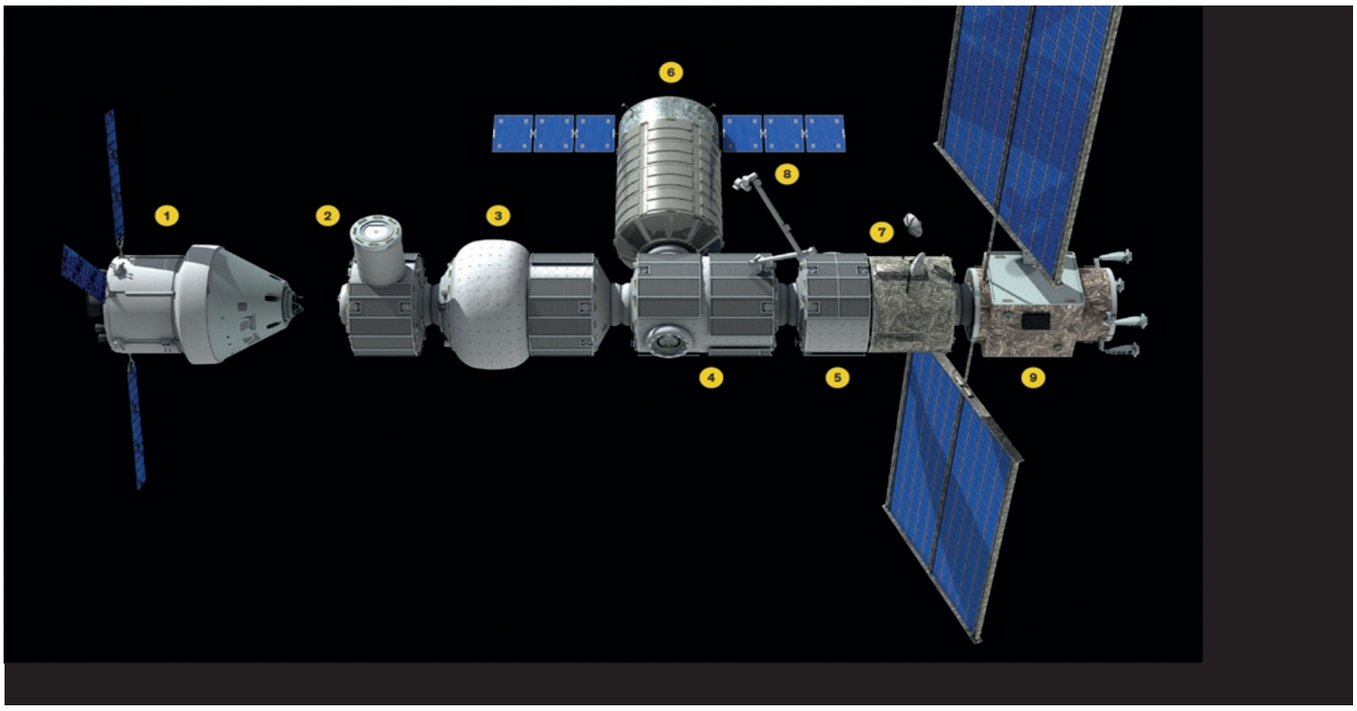

Figure 3: Configuration Concept of the Lunar Gateway. (Labelled numbers refer to above descriptions)

- More liveable room through an increase in the living area.
- Access to the internet.
- Creation of new laboratories.

Such improvements have already been included in the design of the Lunar Gateway to ensure higher quality. Similarly, the provision of a docking station on the ISS, and its old technology along with many deteriorations that came with age also contributed to the need to construct a more efficient Lunar Gateway.

Hence, the new Gateway will surely have enhanced durability and quality as knowledge has been built from the flaws in the ISS. This serves as a remarkable stepping stone that allows for us a whole society to create something better in the form of the Lunar Gateway.

The Lunar Gateway will be built based on several suggestions and principal ideas to create a sustainable and reliable structure. For example, its engine is a highly pioneering and creative design. It will be a 6kW Solar Electric Propulsion (SEP) engine. This design will not only incorporate Maxar-built electronics, but also a Xenon feed system, alongside four Busek-built BHT-600 thrusters. SEP will use solar energy which will later be converted to electricity which will power a Hall Thruster. SEP does not require a great deal of fuel which will assist in long term space travel. NASA has decided to give the contract to construct this engine to Maxar Technologies at $375 million dollars.

Changing to the Lunar Gateway from the current ISS will be challenging. However, it will definitely serve as a novel gateway for humans to grasp a unique opportunity to walk on the Moon and Mars more frequently. Such discoveries and innovative ideas certainly give our society the best chance to evolve beyond Earth, we just need to overcome our fears and act together with one goal, to look at the future through the present with the Lunar Gateway as an evolution of the International Space Station.

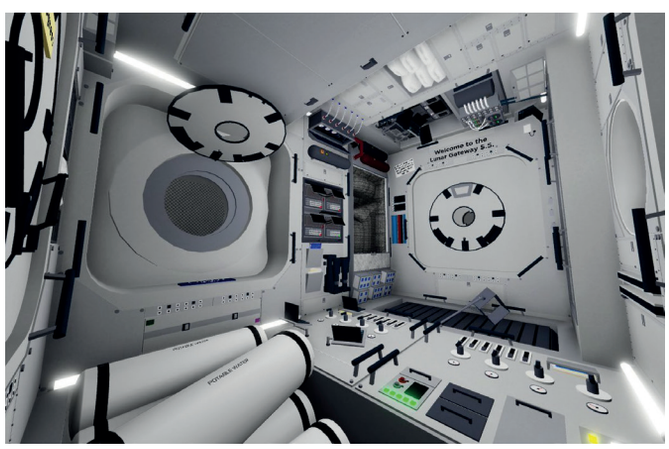

Figure 4: Design of the Lunar Gateway interior

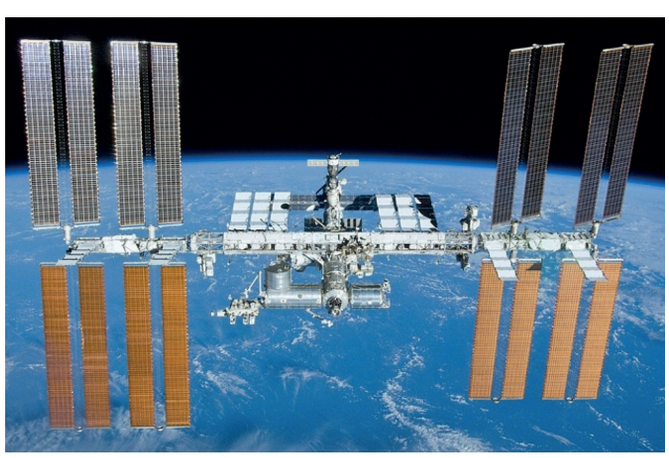

Figure 5: The International Space Station

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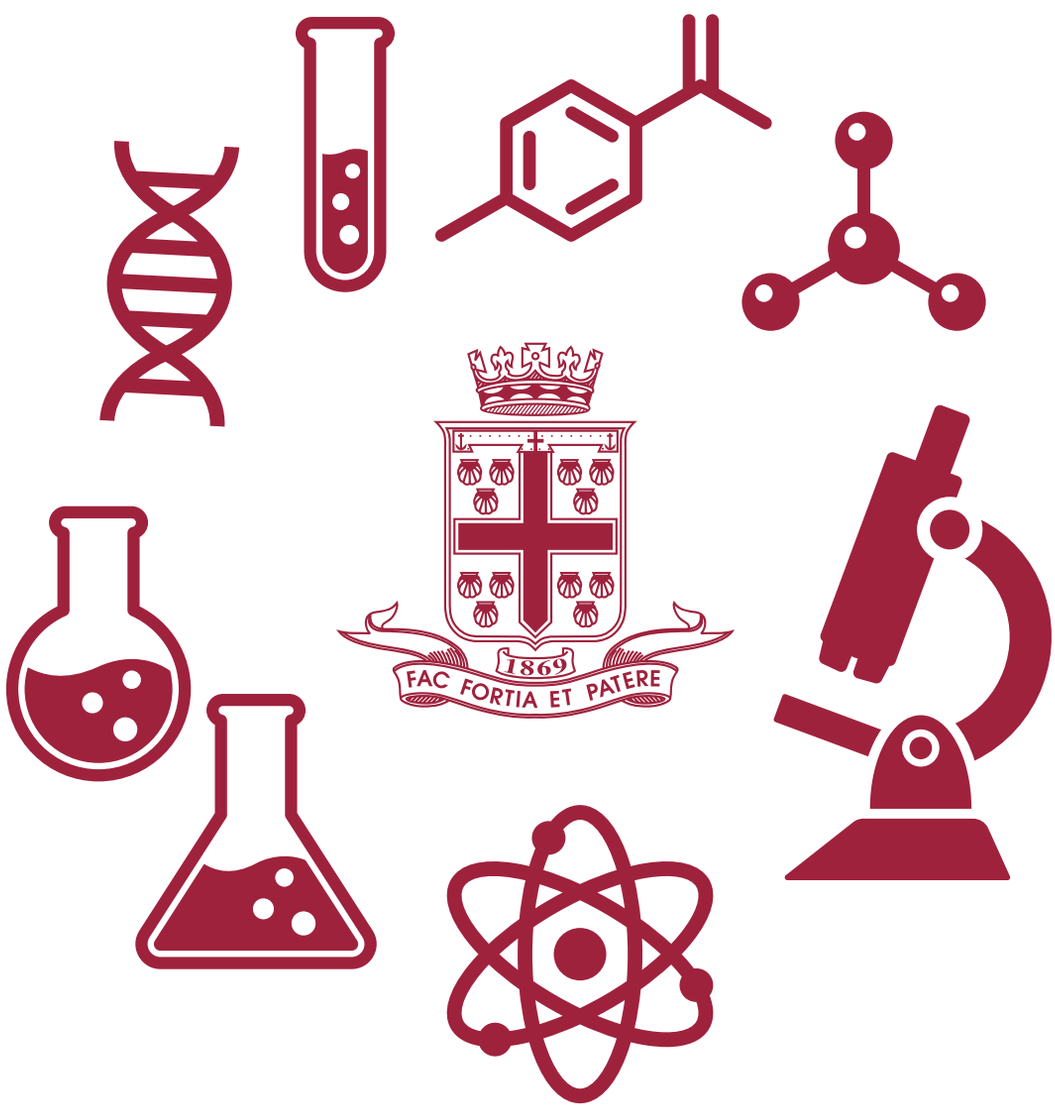
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