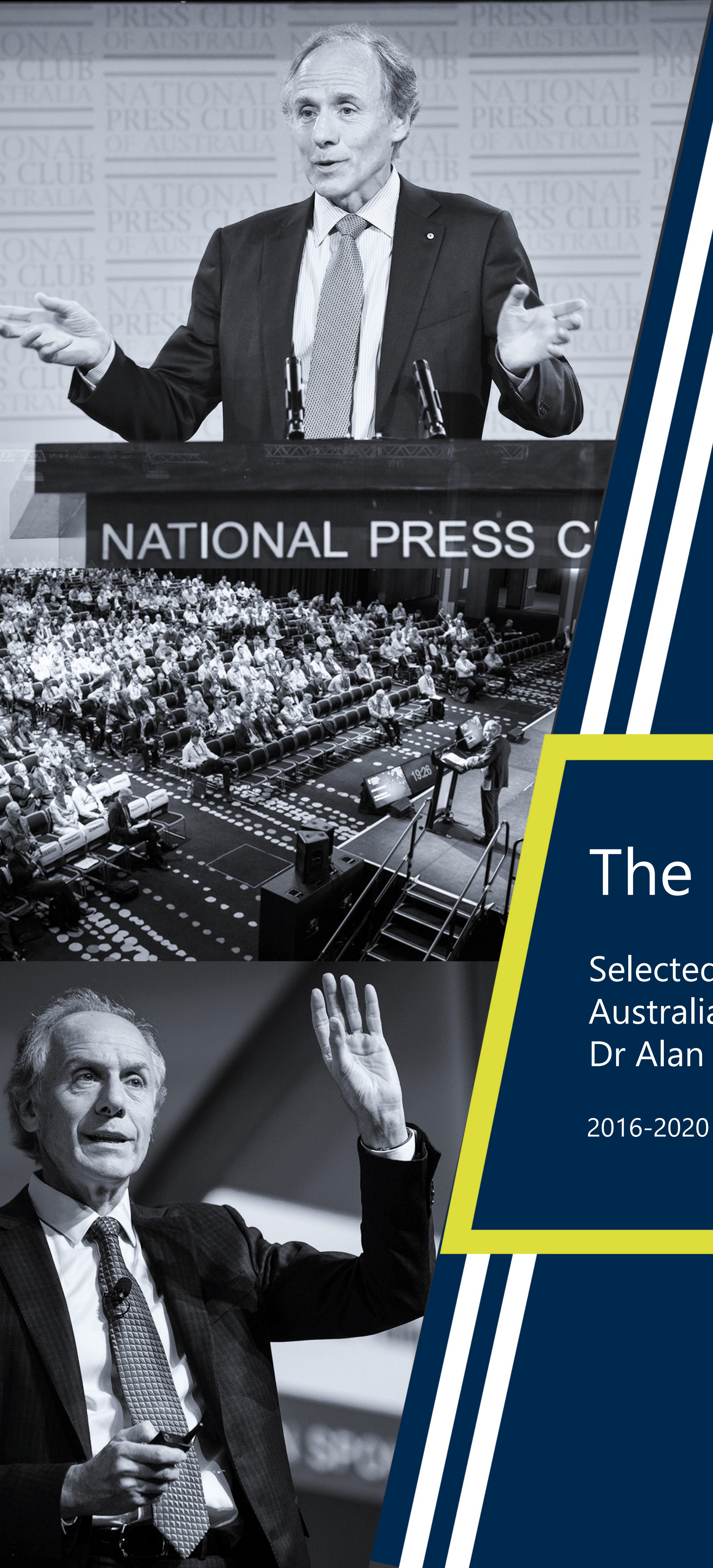

The Finkel Files

Selected speeches from
Australia's Chief Scientist
Dr Alan Finkel AO

2016-2020

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Foreword

Speeches have been my chief means of communication during my five-year term as Australia's Chief Scientist, and I have used them to convey my immense enthusiasm for science and maths, technology and innovation. These are fields of endeavour I was born to, and it was a quite brilliant turn of events to find myself offered the role of Chief Scientist.

The role is threefold: to advise the Prime Minister, the Science Minister and other ministers; to assist the Government in its international scientific activities; and to inspire and communicate with the public. Speeches fall into the third category. Science has brought enjoyment and opportunities around every corner for me and it is my hope that all Australian children will be given the chance to experience the anticipation and excitement of the scientific endeavour.

I have delivered about 100 formal speeches and more than 600 presentations in the role; this collection contains 47 of them. They have been chosen because they chart many of the major tasks with which I have been engaged and they express my optimism about the scientific disciplines. For me, these are subjects without bounds.

Acknowledgements

Being Australia's Chief Scientist is a team effort, which is why I have often referred to an initiative as being "of the Office of the Chief Scientist". In speeches, events and media appearances I have been wonderfully supported by Jennifer Bowles, Jason Deutsch, Matthew Dunn, Warren Fernandez, Kirsten Lawson, Katherine Leigh, Kathleen Horne, Ruth Oettle, Clinton Porteous, Biljana Wenning, Amanda Caldwell, Anne-Marie Lansdown and Sarah Brown. Input and fact-checking came from the policy team in my office and countless public servants over the years. And outside the office, I have been fortunate to have my wife, Elizabeth, as a sounding board, critic and editor.

Dr Alan Finkel AO
Australia's Chief Scientist
December 2020

Preface

As Australia's Chief Scientist over the past five years, Dr Alan Finkel AO has had a remarkable impact.

His intellect and expertise are unquestioned.

But it's his vision and keen sense of engagement that have helped drive a new intersection between science, innovation and the economy that will benefit all Australians.

Dr Finkel played a major role in Australia's response to the COVID-19 pandemic – convening the Rapid Research Information Forum to provide fast, evidence-based answers to ministers and working to strengthen the contact tracing arrangements that proved so critical.

Science is also central to our national resilience in the post-COVID world, not least our energy security. Dr Finkel has helped chart a technology-based energy future for Australia which focuses on the needs of consumers and integrating low-emissions technologies.

In all areas, Dr Finkel has provided rigorous advice based on the best available science, while also showing a unique ability to advocate persuasively – on subjects ranging from climate and disaster resilience to research commercialisation and gender equality in STEM fields.

At the start of his term, Dr Finkel said: "language is the freight-way of ideas."

In The Finkel Files – a collection of his speeches as Chief Scientist – both his love of language and his well-argued and insightful ideas are on full display.

By turns thought-provoking, inspiring and whimsical, these speeches reflect Dr Finkel's bold aspirations for Australia and his unswerving belief in the power of science to improve lives.

As Chief Scientist, Dr Finkel has done our nation a great service.

I know Alan will continue to contribute significantly to the Australian and international science communities in the future.

The Hon Scott Morrison MP
Prime Minister of Australia
18 December 2020

CHAPTER 01

Science and the Nation

“Any national office is a profound responsibility”

Chapter 1 | Science and the Nation

Introduction

I gave up on a career plan when I reneged on my own childhood commitment to be a doctor by choosing to enrol in engineering. Without realising it, from then on, for the rest of my life my career was determined by taking attractive opportunities as they arose.

The most recent fork in the road occurred when I was approached by Julie Steiner in her role advising the Government in the search for the next Chief Scientist. “No, Julie,” I said, “I have plans for next year. Some already in play that would have to be unwound.” But she was persuasive and she talked me down out of my tree and convinced me to at least seek advice from my wife and my business partner. And so, after due process and the passage of time, I found myself as Australia’s Chief Scientist.

Australia’s Chief Scientist has no line management role nor funding responsibility for science in Australia. The role is actually that of chief scientific advisor to the Prime Minister, the Science Minister and other ministers where relevant, with international engagement on scientific matters and communicating to the public thrown in.

Before I started and in the early days, what scared me most was the idea of it being an advisory role. I had spent all my working life in decision making roles, as the CEO, CTO, or chairman of companies and organisations. Nevertheless, working in an advisory capacity as Australia’s Chief Scientist worked out well. It involved all the ingredients you would expect, but the most important is one that surprises many scientists – the realisation that ministers and governments weigh a multitude of factors when making a decision. These include economic impact, competing budget priorities, community sentiment, personal values and evidence based advice. It is not reasonable to expect that they should make decisions based solely on what the science says. Instead, as a scientific advisor, my role has been to help them join the dots.

I have to say, I have greatly appreciated the receptivity of Prime Minister Scott Morrison to what science has to offer, especially this year in the response to the coronavirus pandemic and the formulation of energy policy.

1. Senate Estimates: Opening Statement

February 10 2016 | Opening statement to the Senate Estimates hearings

Appearing before a Senate Estimates committee soon after starting as Chief Scientist, I used my opening statement to explain who I was, as defined by the recent highlights in my career. I set out the broad agenda that I anticipated would define my term. First, investing in the research facilities that would ensure Australia retains its place as a world leader in research. Second, making sure our education system has science, technology and innovation at its core so we're producing graduates who can rise to the technological challenges of the future. And third, preparing for a world where automation plays an ever greater role. As I said then, I wanted to make Australia work for science, and science work for Australia.

What I foreshadowed proved valid, but my five years as Australia's Chief Scientist was packed with so much more. Mammoth tasks just appeared, sometimes overnight, such as the Review of the National Electricity Market, or advising on climate and disaster resilience, and leading our response to acquiring ICU ventilators as part of the COVID-19 pandemic response.

I thank the Chair and the committee for accommodating me in this time slot, acknowledging that I was scheduled to appear tomorrow but must be interstate at an all-day board meeting of a government agency. I am very pleased to have this opportunity to meet with the committee at the outset of my term.

Any national office is a profound responsibility. My commission comes with enormous opportunity. I want to make Australia work for science, and science work for Australia. My experience convinces me that we can be the beneficiaries of our remarkable times.

By background, I am an engineer, migrating into neuroscience. As a PhD student and postdoctoral research fellow, I developed new methods to measure electrical signals in individual brain cells. When I finished my research fellowship in 1982, I saw an opportunity to manufacture instruments that other scientists could use to advance their research. I left Australia for Silicon Valley, California, with my wife, a small amount of cash and a determination to do something different. In 1983, my company was a one-man operation called Axon Instruments. In 2000, it was listed on the Australian stock exchange, and four years later it was purchased by a US public company.

I shifted my attention back to Australia, determined to share what I had learned about science, about business and about the opportunities to be made when the two combine. Since that time I have worked right across the science and innovation community. I co-founded *Cosmos* magazine to share my passion for high-quality science journalism. I have helped to progress new technologies as a company director, and supported science education as a mentor and philanthropist. I have also been an active contributor to the policy debate, as a member of the Research Infrastructure Review Panel led by Mr Phillip Clark, Chancellor of Monash University, and President of the Australian Academy of Technology and Engineering.

> ***"I want to make Australia work for science, and science work for Australia"***

I have approached every role in the firm belief that we can always make more of our resources than we think we can today. The challenge is to reach for the distant targets in a series of measured steps – conducting research, managing risk, and making space for ingenuity and innovation. I have found this mindset to be as helpful in the complex challenges of policy, as it is in building a business or conducting scientific research. This will be my approach to the significant items on my agenda.

I would highlight in particular:

- Chairing the expert group which will map our national science and research infrastructure needs;
- Deputy chairing Innovation and Science Australia as, among other tasks, it develops the 15-year plan for Australian Government investment, and reviews our research and development tax incentives; and
- leading key Commonwealth Science Council projects, to inform us about our progress against the National Science and Research Priorities and to identify our most transformational research.

The importance of these responsibilities has been underscored in my mind by the recent conversation on the priorities of the CSIRO. As the committee will be aware, the CEO of the CSIRO announced last week a change of strategic direction that will affect programmes across the organisation, including climate research. There is no question that Australia needs a continuous and highly effective commitment to climate science, both to meet our national needs and to fulfil our international commitments. Our contribution is particularly important in light of our central role in understanding the climate of the Southern Hemisphere. It is reflected in the National Science and Research Priorities, one of which specifically commits us to: *Build Australia's capacity to respond to environmental change and integrate research outcomes from biological, physical, social and economic systems.*

Innovation and Science Australia board, 2016
From left: Daniel Petrie AO, Professor Bronwyn Harch, Dr Bronte Adams AM, Bill Ferris AC, Maile Carnegie, Dr Rufus Black, Scott Farquhar, Dr Charles Day, Dr Alan Finkel AO
PHOTO: Innovation and Science Australia/DISER

Australian climate research is a broad activity across many institutions and many disciplines including science, engineering, humanities and social sciences. It relies on collaboration and it demands a national approach. Our most immediate national concern must be to ensure that long-term data collections will be funded and staffed; and that the climate modelling capabilities developed by the CSIRO will continue to be made available for scientists to use and refine. I am pleased that the CSIRO has this week committed to working with stakeholders to develop a transition plan to maintain this capacity.

More broadly, we need to approach all our research capabilities as a nation with limited resources and significant needs. This includes appropriate planning for the skilled and qualified people who are the core of our national research endeavour. It will be my priority in the three years ahead to embed this approach in the frameworks that underpin Australian science.

It will also be my particular mission to celebrate Australian successes. To grasp the breadth of our potential, we need to hear about our achievements. And we need to grasp that potential to answer so many of our critical questions:

- How do we put in place new research infrastructure to fuel superb science and innovation for decades to come?
- How do we develop a workforce that is literate in science, skilled in technology and excited by innovation?
- How do we ensure rewarding jobs in a more automated world?

I know that interest in these topics is widely shared across the Government and the Parliament, and I look forward to working with you in the years ahead. My role comes with high expectations. I assure you that I approach them with energy, ambition and commitment.

2. Cresting the Wave: The Voyage of Science and Innovation

March 2 2016 | Keynote Address to the National Press Club for Science Meets Parliament

In pursuit of a dream, between finishing my term as Chancellor of Monash University and starting my term as Australia's Chief Scientist, Elizabeth and I went to Iceland, Sweden and Norway to chase the Northern Lights. We were indeed successful and I have many eerie photos to prove it. While in Stockholm we followed the advice of a friend to visit the Vasa museum that houses the salvaged Vasa warship that sank ignominiously in 1628 about 10 minutes after it set out on its maiden voyage. Many historians see the Vasa as a symbol of the past glory of Sweden and the international projection of power. I saw it is an indisputable example of political intention clashing with the laws of physics. Unsurprisingly, the latter prevailed. The fact that the first two minutes of my speech to the National Press Club at the beginning of my term described a collaborative, international shipbuilding effort by a small nation might have led some in the audience to assume I was referring to Australia and its newly minted naval procurement program, but that was not the case. The main intention was to convey the essential role of science-based innovation in providing the solutions to our needs. This speech focuses on the need to get the settings right to inspire, enable and support scientific advances and new technologies. The arrival of self-driving cars, for example, has the potential to dramatically reduce accidents, but also to increase traffic and congestion. They also require a big investment in sensor infrastructure, and they require a blackout-free internet network. Each piece of new technology comes with these kinds of challenges that must be addressed ahead of time – and in themselves represent opportunities for a country like Australia. My term as Chief Scientist has focused on setting the groundwork for this innovation agenda, through a review of the research and development tax incentive (September 2016), a National Research Infrastructure Roadmap (February 2017), and contributing to the innovation plan, Australia 2030: Prosperity Through Innovation (November 2017), developed by Innovation and Science Australia.

Let me start with a story about a small nation with middle-power ambitions. It's a nation in transition. Its population is growing. Its commodity-based economy is booming, on metals and minerals and grain. That growth is supported by a strong financial sector and a sizeable migrant workforce. It is underpinned by landmark tax reform bedded down a few decades ago.

But this small nation is well aware of its uncertain place in a strategic region at a volatile time. So it embarks on a bold exercise in next-generation defence procurement: a flagship for its navy and a statement about its place in the world. The construction and financing is a public-private partnership. The work is outsourced to a foreign company. That company subcontracts in turn to an international consortium of SMEs. And then they head into an old-growth forest to source the materials. A forest – because this ship will be built of oak.

The setting is Sweden, 400 years ago, in 1625.

Big dreams, epic failure

Now this was no ordinary ship that the Swedes contracted the Dutch, who subcontracted the Germans, Danes and Finns, to build. This was something that no-one in Sweden had ever attempted before: a 135-foot warship with two decks, each bearing 36 cannons. And it had to be built on the keel of the 110-foot, one-deck warship the contractors were initially instructed to build.

That ship was half done when the King changed his mind, inspired by the thought of an extra deck, with extra cannons. So the builders set to work, and they did their best to adapt the keel, while the King went off to fight his war with Poland. By August 1628 the ship was ready.

All of Stockholm gathered at the harbour for the launch of this mighty symbol of Swedish pride. And all of Stockholm was still there when, 20 minutes after the launch, tilted by the gentle nudge of a light sea breeze, it sank – less than one nautical mile from dock.

This ship – the Vasa – has sailed into business school history – as the textbook case in innovation done wrong.

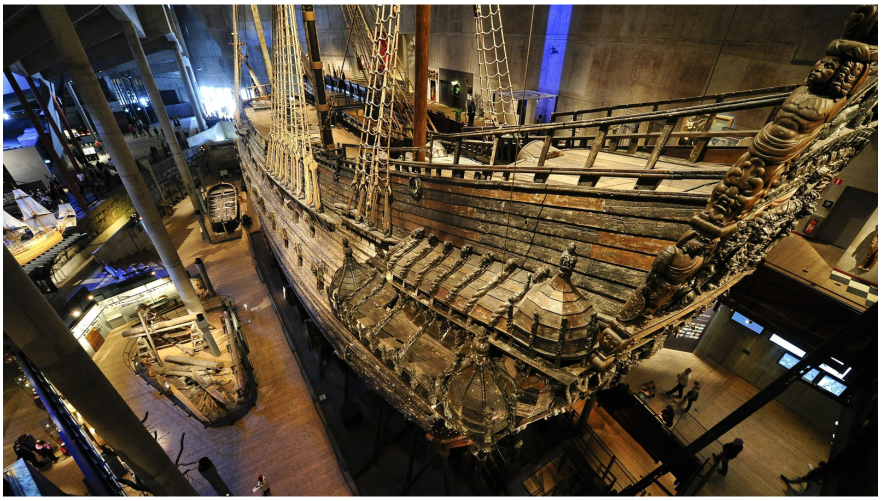
- Project specifications that changed at political whim
- A workforce of 400 people, the largest workforce ever engaged in a single project in Sweden, split up into five autonomous project silos
- No evidence of design plans
- No prototype before the full-scale model was built
- No appetite for frank and fearless advice – the giving or the receiving of it
- No testing until the very last stage – and then no courage to halt the launch when the tests confirmed the outcome would be catastrophic
- Money squandered on vanity projects – including 20 busts of Roman emperors facing off against some ornamental mermaids
- And above all, not enough science

The ship and 53 lives were lost as a result. When investors say they are risk-averse, here's the reason: no-one wants to go down with the two-deck ship.

Learning to innovate – intelligently

You might say it's risky to start a speech with failure. But I've never been afraid of risk. And I can tell you that no modern engineering team would build the Vasa today. I'm assuming, of course, that at least one member of the team would have come within spitting distance of Newton's laws of physics in the course of their training. But the Vasa was about six decades too early for Isaac Newton. The shipmasters did not know about force vectors and how they sum, or the significance of the centre of gravity. So they were effectively blind, where modern science gives us the power to see. The more we know, thanks to science, the more we can achieve through innovation. And the more efficient the path we take to get there.

Elizabeth and I visited the Vasa Museum in Stockholm in January. When I heard the story, I immediately knew that I would have to include it in my maiden voyage as Chief Scientist at the National Press Club.



The Vasa at the Vasa Museum in Stockholm
PHOTO: VRACK Museum of Wrecks

The first thing that the story of the Vasa says to me is this: if we want bold solutions in this century then we need science – and plenty of it.

As important as it is, though, science is not enough. We need to think about interactions, unexpected consequences and the management of risk. If we were to build nothing new before we were absolutely certain we knew the best way to do it, that would be the end of progress. And even if we did figure out the quantum world tomorrow, even if we did have a grip on the fantastical complexity of the human brain, even if we did crack nuclear fusion, there would still be questions about the practical ways our knowledge might be applied.

Take self-driving cars. Now I'm not drawing a direct parallel here to the Vasa – I know which of the two I'd rather travel in, and it's not the one with ornamental mermaids. But I will put it to you that we are in our own way launching an untested craft into unknown waters, with consequences that we can only foresee in part.

There are plenty of benefits – mobility for the elderly, fewer accidents, freedom to talk on your mobile phone. But is it that simple? Say you're in the city to attend a meeting. Do you pay for the car to park, or do you just send it round and round the block for the duration of your meeting? Congestion would skyrocket. Say it's 8 am on a school day. Do you carpool, or pack the kids off and wait for the car to return, again, and again? More congestion!

But the harder questions for government only proceed from there.

- How do we deter people who think like me from adding to traffic congestion?
- Who do we allow to own or direct these cars?
- What happens to all the people who today drive things like trucks and taxis for a living?
- Who builds, and then who takes responsibility for, the sophisticated networks of sensors to support the cars?
- And given that orderly traffic flow depends on the interconnections between the cars and the traffic management software, what happens when a car hits an internet blackspot? Potential catastrophe.

These are but a fraction of the issues attached to one technology in the immediately foreseeable future. To solve them, we need not just science, but research. Where research is the investigatory collaboration between science, technology, sociology, economics and the like. In all of the complex challenges that technology will bring, the humanities, arts and social sciences are critical to our research endeavour and we neglect them at our cost. Combine these research elements, and we will reap the benefits: Gridlock gone. Crashes avoided. Carparks repurposed. Designated drivers extinct. Backseat drivers forever silenced.

And if you can imagine that self-driving car then you can also imagine a low-emissions electricity grid supplying electric vehicles. Connected to fantastic arrays of solar panels in the outback.Travelling through an ever more exciting world. Perhaps by then we've made progress towards bionic eyes for the vision impaired. Or launched trips into space for tourists. We could be living in an Electric Planet.

PHOTO: Mark Graham

A zero-emissions world

How much progress could your lifetime contain? We decide – and not just by the scope of our ambition but by the breadth of our research, the quality of our planning and the calibre of our leadership.

So science is vital, and innovation takes hard work – two lessons that a shipwreck can teach. Learn them, and we will prosper in our own remarkable times. With great science we will create great research outcomes. With clever innovation we will turn those research outcomes into societal and economic benefit. With great science and clever innovation combined, we can discover how truly remarkable we might be.

Applying the lesson to public policy: the vision and the path

As a student, researcher, innovator and investor, I've always tried to keep the doors of opportunity open. I've reflected a great deal recently on what chasing opportunity means for public policy. After all, Australia has embarked on one of the most ambitious public-sector innovation projects we have ever attempted.

> *"How much progress could your lifetime contain? We decide – and not just by the scope of our ambition but by the breadth of our research, the quality of our planning and the calibre of our leadership"*

Its aim is set out in the National Innovation and Science Agenda. We are seeking the design specifications for a very different sort of country, a country with the scientific potential, the industrial capacity and the startup culture to thrive in the decades ahead.

Above all, it's about thinking and operating at scale. If you recognise a problem is big, you will be more likely to develop appropriately large-scale solutions. For example, although Australia has the largest rate of rooftop solar installations in the world, the total contribution to our electricity needs is just 2.1%. Electricity itself only represents about a fifth of our total energy consumption, so the contribution of solar today is still tiny. We've done wonders with solar from a virtual standing start in 2010, but to get to where we want to be we need to move faster, with bigger ambitions.

Operating at scale is not just about distributing money. The goal has to be to create an environment that encourages success. Take red tape. It's the gift wrap for opportunity. For example, our existing regulations make it easier to test unmanned aerial drones in Australia than it is for developers to test them in the United States. So we have an opportunity to be a leader rather than a follower in the use of drones for media, mining, retail and sport.

Our regulations also support an efficient, world-class clinical-trials industry, a national asset we ought to celebrate. Every year, around 1000 new clinical trials commence in Australia, capturing a $1 billion dollar investment. But we don't create the same supportive environment for manufacturers of medical devices. Why not aim to win on all fronts, in the interests of consumers as well as workers and investors?

Beyond regulation, we need a highly educated workforce, and tax regimes that are simple, reasonable and fair. We need to ensure that the government's contribution to the innovation system is not too complex. And when designing an environment to encourage innovation we need to declare in advance how we will measure success. We are capable of creating this environment, and where we succeed, good things happen.

Let me give you some examples from my first month on the job. I do not take credit, but I do take note, as should we all. In basic science, we've observed gravitational waves. Easy to say, but so difficult to do that Einstein himself thought we'd never crack it. To me, this was the most exciting announcement in physics in my lifetime. It rounded out Einstein's theory of general relativity.

The event was observed by an instrument, to which Australia made important contributions, that is the most sensitive combination of physics and engineering ever contemplated. Most important, we now have a whole new way to observe the universe. More than 400 years ago Galileo improved the optical telescope so that he could use it to prove that the Earth revolves around the Sun. In the 1930s, the radio telescope was invented and eventually used to discover pulsars, quasars and the cosmic microwave background radiation. Now, the optical telescope and the radio telescope have been joined by a gravitational telescope. With it, we will discover things we never imagined.

Back on Earth, in the marketplace, we've seen Australian science in translation, in the form of a $730 million licensing deal in which the pharmaceutical giant Merck acquired rights to a new drug to treat lymphoma, sickle cell anaemia, lung cancer, breast cancer and colon cancer. And then Atlassian powers on, after sparking the dreams of a million ambitious young people when it listed on the US stock exchange and reached US$5.8 billion overnight. It's a classic story of two Sydney science and IT students who developed planning tools for software developers, a product that was so good that it sold itself without a sales force.

Good news. Good news across the spectrum from scientific discovery to commercial success. Good news that stimulates the imagination. And if you think we've exhausted the tank, if you think we've optimised the policy settings, it you think this is as good as we can get, you're wrong.

How many women give up on promising careers in science, technology, engineering and mathematics? Women comprise more than half of science PhD graduates and early career researchers, but by their mid-30s a serious gender gap starts to appear. We are improving – but we have a long way to go.

And how many businesses don't engage with universities or research agencies? Enough to rank us at the bottom of the OECD for cross-sector collaboration.

> *"With great science and clever innovation combined, we can discover how truly remarkable we might be"*

How many researchers were never encouraged to think about working in industry or creating a startup in the course of their training? Too many, because we still set PhD students' sights on academic careers, even if for the majority we can't possibly satisfy the expectations we create.

And how many good ideas might be waiting to be turned into products or processes in our research facilities? We've got great universities – but none in the Thomson Reuters list of the Top 100 University Innovators. We rank 9th in the Global Innovation Index for the calibre of our science institutions – but 72nd for innovation output.

I'm telling you all this bad news because there's a silver lining. Just think what this country might achieve if we address these issues. Then Australians can get on with bringing the future into the present.

Linking to my agenda

"So what are you doing about it, Alan?" you might ask. Lots, is the short answer. Enough to weigh down a speech like 36 cannons on a 17th century ship, is the longer one.

So let me signpost some of the work to expect from my office in the year ahead.

First, there's my role at Innovation and Science Australia under chairman Bill Ferris, to help lead the development of a 15-year plan for investment in science, research and innovation. It's the strategic plan for the country, and it will be critical to coordinate the many moving parts in play.

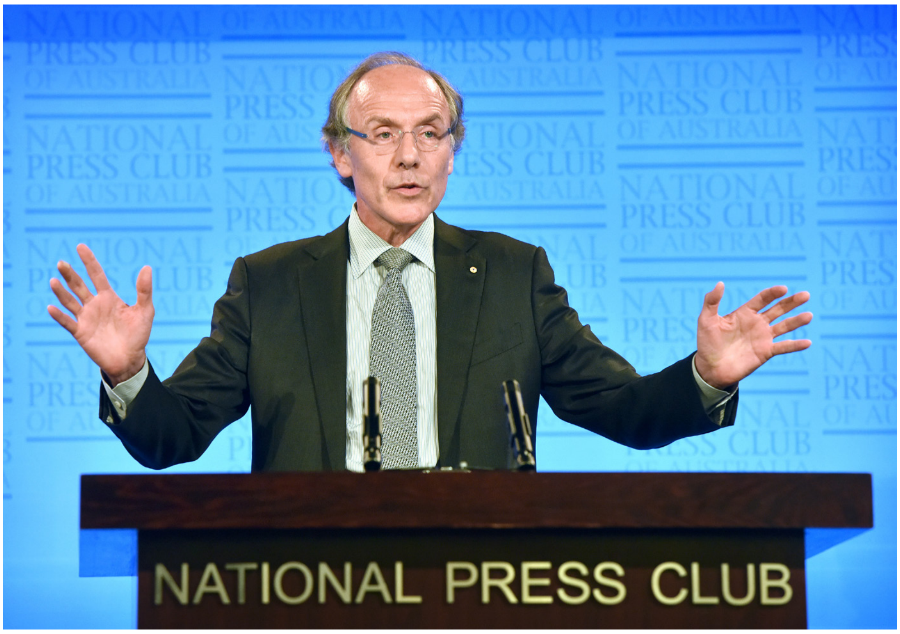


PHOTO: Mark Graham

Second, Bill and I will be joined by John Fraser to undertake a review of the R&D Tax Incentive. Yes, it's been reviewed several times. But as we gather more data from the operation of the program there is an opportunity to further refine the incentive to ensure that it is effective at encouraging R&D that would not otherwise take place.

Third, I will be leading the development of a roadmap for our future national research infrastructure. This term "research infrastructure" is a little clunky because when we hear "infrastructure" we usually think of the everyday things – the bridges, ports or railways we know so well. We don't think of the infrastructure that maps the cosmos, images the brain, explores the oceans, and archives our history and stories. But we should, because it enlarges our capacity to reach for the future. If endorsed, the proposed new infrastructure identified in the road-mapping exercise will power Australian research in coming decades. And if history is our guide, powering science translates to fuelling industry, and putting Australian innovations out to the world.

Fourth, there's the work of the Commonwealth Science Council, for which I am the executive officer. We will measure progress against the nine National Science and Research Priorities, so we can answer to the expectations of Australians. We will identify our most transformational research, and we will scope the big future opportunities for Australia.

Finally, a word about education. I came to this role with the experience of creating three ongoing education programs, two in schools and one for early career researchers. So it makes sense that, building on the Office of the Chief Scientist's existing capability, I intend to present the data that will help to elevate our ambition for Australian schools.

We must reverse the slipping rankings of our students in international tests. In 2007 we were ranked at around 10th in the world. By 2011 these numbers had deteriorated and Australian students were significantly outperformed by 18 countries in science and 17 countries in maths. Being out of the top 10 is bad enough, but being on a downward trajectory is even worse.

What can we do to reverse this trend? Numerous concerned individuals, institutions and companies have created extracurricular activities to try to stimulate interest in science. My office has just published a listing of the extracurricular STEM initiatives around the country and during the course of this year we will work to make it available as a dynamic database accessible to all teachers, students and parents.

But this will not be enough. The scale of the challenge is huge. We need to enhance our in-curriculum teaching capacity. We need to ensure that students learn deep content, not just how to learn. And we need to challenge our students and support them to meet those challenges.

All up, a three-year term as Chief Scientist doesn't seem quite long enough. But as a travelling engineer I have learned to pack efficiently.

I began with the Vasa gunship. I'll end with its postscript. It sat on the bottom of the harbor for 333 years. Then it was raised in 1961, almost perfectly preserved, ornamental mermaids and all. Raising it was a phenomenal feat of ingenuity and engineering. It was installed in a purpose-built museum, where more than a million people every year line up to see it.
To Sweden, the Vasa is now a great source of national pride. Because Sweden didn't give up on building ships. They built two-deck gunships. They built three-deck gunships.
Gunships that became the pride of the Swedish military for the next 30 years. They helped to usher in the age the Swedes call stormaktstiden – the Great Power Period.

Failure, repurposed as a symbol of success. But we don't have to get there from the bottom of the harbour. Let's take the direct path to our own stormaktstiden, our Great Power Period.

3. Evidence and Integrity

February 13 2018 | Speech to Science Meets Parliament

Scientists often find the public face of their work – the way it is portrayed in media and politics – frustrating. This speech, to a Science Meets Parliament gathering, aims to help scientists negotiate this interface, with a reminder that integrity and evidence remain at the core, daily headlines are not the longer story, and the message needs to be delivered in a way that is useful.

My approach in each of the reports I have prepared for the Government and commissioned on its behalf has been to consult widely to ensure we answer the question asked in the best, most rigorous, useful and contemporary way possible. The Horizon Scanning reports, commissioned for the National Science and Technology Council, aim to ensure Australia is focused on emerging technologies and is prepared for them. Six of these reports have been prepared by the Australian Council of Learned Academies to date, on the topics of storage in the energy mix (2017), precision medicine (2018), the deployment of artificial intelligence (2019), agricultural technology (2020), synthetic biology (2020), and the Internet of Things (2020).

Another way in which we have sought to bring science closer to policymaking is the Science Policy Fellowship program, in which mid-career scientists are offered a year working in government departments in Canberra. This pilot program, launched in 2018, has provided placements for 31 scientists to date across 11 Commonwealth government departments.

A third initiative is the Rapid Research Information Forum I convened in 2020, in which science academies and institutions provide brief and fast-turnaround answers to questions from ministers, synthesising the available evidence. This began with a series of questions related to the coronavirus pandemic.

We're in Canberra. You're about to meet a lot of politicians. So let me start with an opinion poll. Hands up anyone who regards Isaac Newton as a personal hero. Isaac Newton was not just one of the greatest scientists of all time. He was also a Member of Parliament. It's true. He served two terms as the Member for the University of Cambridge. Legend has it that he spoke in the House of Commons on only one occasion, when he asked for a window to be closed. There you have it. You can write down the Laws of Motion, and have nothing to say on laws or motions in parliament at all.

That's not to say that Isaac Newton wasn't political. On the contrary, he was highly political. He reigned supreme as President of the Royal Society for an uninterrupted 24 years. That's longer than the last six chief scientists of Australia put together. His term only ended when he was buried in Westminster Abbey. So yes, Isaac Newton was good at politics. But he didn't see parliament as a forum for advancing science. That's just the way it was in the 17th century. If you wanted money, you wrote to the king. If you wanted to cut up corpses, you made friends with the local hangman. If you wanted to make a better telescope, like Isaac Newton, you just ground the mirrors yourself.

“Science needs parliament to understand its place in the national mission and parliament needs science to forge an Australian identity – to give us courage, ambition and pride”

So science and parliament could be casual acquaintances – a few shared interests, a bit of shared history, nothing more. That's all changed. Now, science and parliament meet as an old married couple, each reliant on the other. And every scientist knows it, because we've written grant applications. But let me emphasise just how fundamental this relationship is to everything we do. Beyond the money. Beyond laws and regulations. Beyond the tax incentives. Beyond the schools and TAFEs and universities. Beyond them all, we share a purpose. Science needs parliament to understand its place in the national mission. And parliament needs science to forge an Australian identity – to give us courage, ambition and pride. You could, in theory, run a country without reference to science. And you could run science without any organised support from the country. But we tried that. We called it the Middle Ages.

* * *

People tell me that 2017 was a terrible year, the worst year on record. Really? I look back, and I see that gravitational-wave detection has opened our eyes beyond the electromagnetic spectrum. For the first time in the history of humankind we can feel the universe in addition to seeing it! Immunotherapies are opening a new battlefront against cancer! We can sequence the genomes of ancient humans from DNA extracted from skeletons more than 10,000 years old! We can sequence your genome for about $1000. That's one 10,000th of the price just a decade ago! Space telescopes are detecting exoplanets! Scientists have devised an atomic clock small enough to fit on a chip in a smartphone! Elon Musk has just fired a Tesla Roadster on a billion-year voyage into space!

And if none of these things make you leap up from your chair with the joy of being a human being alive today, look around the world. Look at the reality of scientific progress. The proportion of children who die before the age of five has halved since 1998. The number of measles cases has plummeted by a factor of six since 2000. In your pocket, you have a device that combines the genius of OLED touch screens, artificial intelligence and machine learning. Your personal atomic clock is on the way.

Every one of the above is a result of decades of scientific research. Funded by government, undertaken by scientists. Science met parliament, and the offspring was progress. And its sibling is potential.

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So, the big question. The state of the union. I would say, like all relationships, it needs work – and sometimes, it can benefit from counselling. If science and parliament walked into my office, and asked for my advice, as a person who talks to both scientists and politicians, I would say four things.

First, to the scientists: the same rules and standards you apply to every other part of your professional life apply here as well. We are scrupulous about those standards amongst our academic peers, because the scientific method is printed on the inside of our eyelids. It reduces to two things. Hypothesis, and evidence. The best science has both, hypothesis and evidence. Hypothesis alone is a good start. Evidence alone is a good start. When they are both absent, it's not science. When they are both present, it's brilliant science. That's how science delivers the goods, and why it's worthy of confidence and respect. That's the standard for a scientist in the conduct of research. It's the standard for a scientist advising politicians on policy in Canberra. It's the high bar.

Other people who speak to politicians will over-promise, gloss over the risks, understate the costs, or try to play multiple people against each other in various cunning ways. That's their game, and sometimes, it probably works. That doesn't mean we scientists can afford to do the same, to lower the bar. No, a low-bar scientist is not a scientist. I promise the politicians you meet will welcome you with genuine interest, enthusiasm, and respect. Now be aware, they will be guided by factors beyond scientific evidence. But that's exactly as it should be. It doesn't mean that they expect less of you. They trust us to clear the high bar.

We need to ensure their trust in the strength and potency of the scientific method we represent. To ensure their trust, we must be vigorous as a community to maximise the quality of published science. We are ambassadors. Every scientist needs to uphold the collective credibility of science by absolute integrity in all our dealings with the media, the community and politicians. Integrity means don't exaggerate. Integrity means share the bad as well as the good. Integrity means don't trivialise. I know you take this responsibility seriously. I try to keep it uppermost in my mind.

So, first principle for a happy marriage: be true to the highest standards of the profession.

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Second, to scientists and politicians: you're in it for the long haul. For better, for worse; for richer, for poorer, you're in it together. Look beyond the here and now to the things that endure.

The impression you get from the media is that politics is a B-grade movie – bad dialogue, all violence, no plot. But the science that politicians see on the television is equally superficial. They see the highlights: discoveries and breakthroughs and prizes. You know the reality: there's a context, and a logic, and lot of work.

The same is true of parliament. Connections in Canberra are enduring, and relationships count. The MP you meet today through a committee could be a minister in five years' time. A junior public servant will be a senior public servant. Beyond the people, there are practices – protocols, conventions, expectations and rules.

And there are patterns. The political seasons in Canberra are as rhythmic as summer to autumn, winter to spring. Autumn leaves, it's Budget. Spring blossoms, parliament returns. If you know the patterns, you can till the ground, plant the seed and grow the flowers. It would be fascinating to see how many projects have bloomed through all the years of Science Meets Parliament.

Perhaps you're attracted to a career in policy but would like to test the waters. In that case, consider an application to a new scheme established by my office. This year, for the first time, we opened a Science Policy Fellowships program, offering a full year's experience working directly in government departments, here in Canberra. Twelve mid-career scientists starting in July will take a year off from their research to work in a science policy role with one of seven Commonwealth departments. Applications will open again towards the end of 2018. Keep it in mind. But even if you're not in Canberra to stay, think about that advice: for a happy marriage, take the long view.

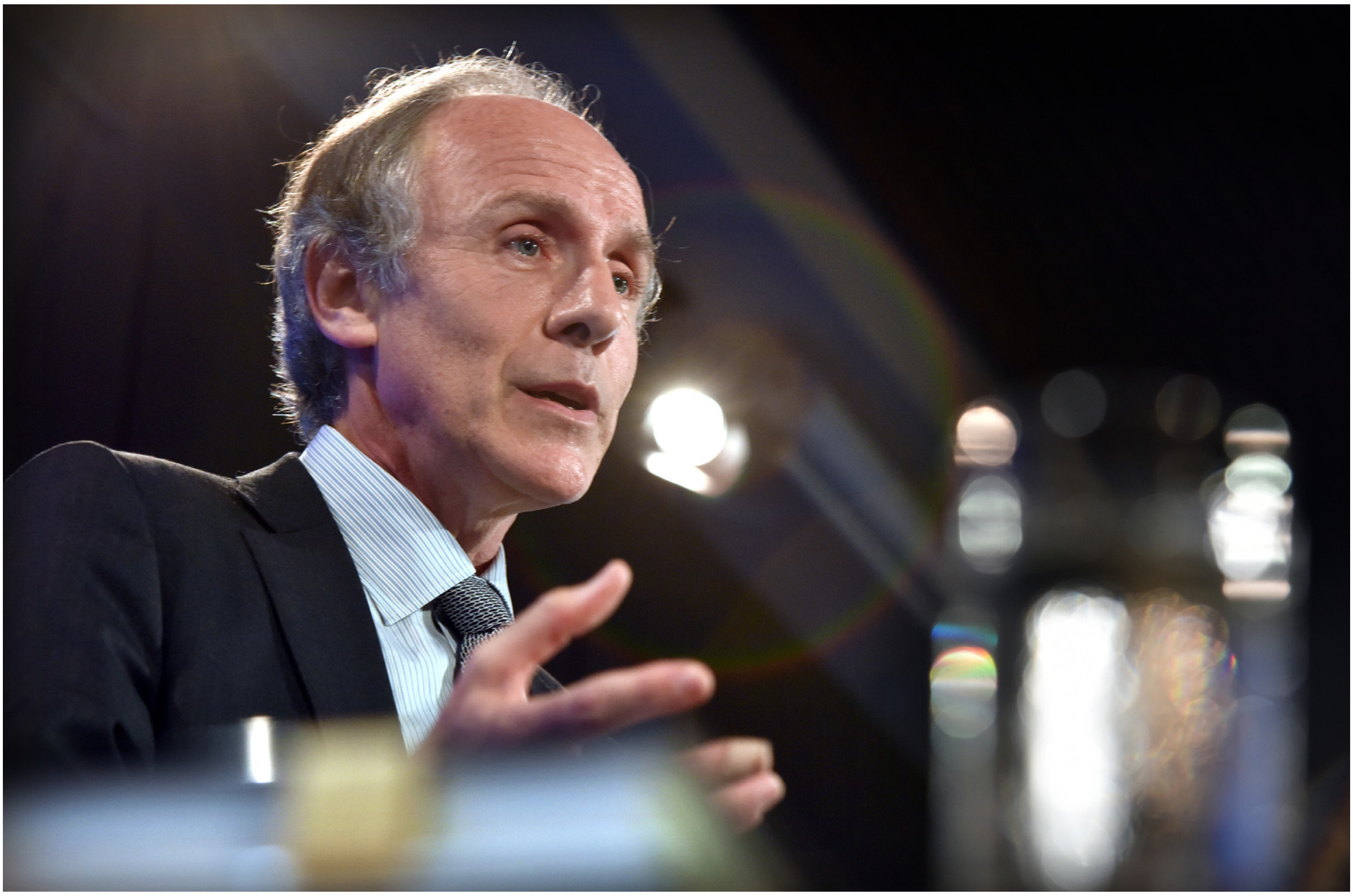

PHOTO: Mark Graham

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Third piece of advice, communication is key. The secret of good communication is to keep your audience in mind. I say this in some academic forums and people recoil: Science is independent! Yes, science is independent of bias and coercion and self-interest and partisanship. See Rule 1 above: integrity and rigour are non-negotiable.

But communication is not independent of the audience. Otherwise, it's not communication, it's just content. Thinking of your audience doesn't mean changing the content to suit the other person's worldview. It means explaining where the content fits, in the context of the goals you share. Start not with "I want" but with "we can help each other to achieve".

Ignore anyone who tells you that politicians or people in general are incapable of absorbing complex ideas. Not true; they can and they do. Here's my proof: the topic of precision medicine. To date, that phrase has never been spoken on the floor of the Parliament. Search Hansard, the written record. You won't find it. But there's a golden opportunity for all politicians: be the first. The first to use in Parliament a term that transforms our understanding of health, and adds years, maybe decades, to our lives.

The idea at the core of precision medicine is simple and compelling. Healthcare should be optimised to the individual. Tailored to you, based on your own gene sequence and your own medical and health records, taking advantage of every insight we can glean from a world awash in data.

Innovation and Science Australia has laid down the challenge in the 2030 Plan: let's make this ambition of custom-made 21st century care, for everyone, a defining national mission. That means more than knowing the term. It means mastering the concept in depth.

The ministers who sign off on the decisions need to be confident that their judgment is sound. How confident? How confident would you want to be before you tried to restructure the healthcare system in real time, with real patients, real families, real consequences? You'd want to be very confident.

The Australian genomics community has worked incredibly hard to bring politicians to that point. First, by coming together in the Australian Genomics Health Alliance. Second, by explaining the potential through the stories of patients. And third, by making space for the policy discussion. I've been proud to be associated with that process.

As you may know, I am Executive Officer of the Commonwealth Science Council – the body chaired by the Prime Minister. Last year, the Commonwealth Science Council identified precision medicine as a critical issue. I commissioned the Australian Council of Learned Academies, ACOLA, to prepare a report drawing on the skills of the learned academies. The Department of Health declared itself to be interested. Knowing this helped ACOLA to decide the context of its analysis. Not only was the report rigorous and independent, but equally important, it was relevant. That report was launched last month by Minister for Health Greg Hunt. As a model of academic communication – independent expert to political decision-maker – you can't do better.

The report challenges its audience to grapple with difficult questions but it gives them the tools. And the conversation doesn't end with the report. The report frames the discussions to come. The same approach will be used again in coming months, with horizon scanning reports on synthetic biology, artificial intelligence and the Internet of Things underway.

So number three: communication is key.

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And that brings me to my final piece of advice for a happy marriage: keep up the maintenance and renovations. It happens in every marriage. The carpets need replacing. There are too many kids, we need a new bedroom. The tap in the bathroom leaks. It's got to be done. It just has to be prioritised.

The conversation about national research infrastructure often runs the same way. We know if you neglect it, it gets more expensive. If you manage it job by job, without a plan, you spend more money on things you're not completely sure you want. And, of course, if you can't agree, you don't get anything done at all. The way to get things done is to identify the priorities and plan the investments.

Over the past two years, the research community has come together to present government with a roadmap for our national research infrastructure. I was proud to lead that process, and I am working closely with the Department of Industry, Innovation and Science, and the Department of Education to translate the roadmap into an investment plan. I would say to science and parliament this is a priority.

So, there's my four pieces of advice. One, rigour and integrity in everything we do. Two, remember that we're in it for the long haul. Three, communication is key. And four, keep up the maintenance and renovations.

Enjoy your time in Canberra. And one parting shot, a three-word slogan that every politician can borrow: science is fantastic. Let's make this a meeting that no one could forget.

4. Energising Progress

February 24 2016 | Speech to the Australian Summer Study on Energy Productivity Conference

This speech was prescient. It was delivered at the start of my term, before I had any idea that I would become deeply engaged in the world of energy security and low emissions. The story in the speech about the advances in room lighting illustrates the essential role of energy and technology in the progress of civilisation through the ages. An economist named William Nordhaus developed the yardstick of the amount of light produced by a 75 watt incandescent globe operating for one hour. Back in ancient Babylon, a labourer would have toiled for 40 hours to earn sufficient shekels to pay for sesame oil to run a lamp to produce that much light. Today, an average labourer would have to work for less than a second to pay for the electricity to run an LED lamp to meet the yardstick.

We are facing a climate change crisis. We can't afford to wait 4,000 years for incremental changes to deliver the improvements that Australia needs in energy productivity alone. It will take new technologies, delivered at huge scale. This speech, at the Australian Summer Study on Energy Productivity at the start of my term, gave examples of new technologies that could help tackle the emissions challenge: geopolymer cement, made by chemically binding two industrial wastes, which results in up to 80% fewer carbon dioxide emissions than traditional cement during production; and a magnesium alloy that is much lighter than aluminium and could significantly reduce transport emissions if used to build airplanes and cars.

About 20 years ago an economist named William Nordhaus wanted to change the way we think about progress. But how do you measure progress across millennia? The Big Mac index is too new, and CPI makes no sense. The yardstick he chose was light. Think of a single 75 watt, incandescent light globe operating for one hour. Now imagine how hard the ordinary person would have to work at various points in human history to produce the equivalent of that incandescence.

If you were an ancient Babylonian, you would have a sesame oil lamp, and you'd need to work for 40 hours to pay for that much light. If you were a French Revolutionary, you'd have candles, or perhaps flaming torches, costing you five hours. If you were a Late Victorian, you might have Edison's carbon lamp, costing you 45 minutes. If you turn on that light globe today it costs you less than half a second. You can have, for half a second of your work time, the light for which a Babylonian would be working all week.

Now if we were content to get by in Babylonian darkness, we would have no problems. Except for the fact that we would be living like ancient Babylonians, subject to starvation, disease and boredom. And that, indeed, was what life was like, for the overwhelming bulk of human history, in the millennia between sesame oil and steam. Step back 200 years and you might as well step back to the Stone Age. But crack clean, cheap energy and you shoot to the Space Age. To get there, we need energy. Energy drives progress, progress delivers more energy.

Beyond incrementalism

Our aim is to supply people with the energy to make better lives. We also want to reduce the burden that this goal imposes on the planet. It follows that we need a big goal in energy productivity, such as to double it by 2030. And the bottom line is this: on the plotline of the story that we're starring in, we don't get to that goal in time.

It seems that whatever we do, it's not enough. Markets and regulation will get us part of the way. But they work best when they help take us to the next level. We need science to break through the barriers of possibility. And we need innovation to deliver the solutions. All of this has to be done at scale. Huge scale. In all sectors of the economy.

Let me make that concrete. Take cement. We use more than four billion metric tonnes globally every year, and every year that grows by another few hundred million tonnes. Producing that cement accounts for nearly five percent of carbon dioxide emissions.

Now imagine we can meet that same need with a geopolymer equivalent. We can make it from the chemical activation of two industrial wastes – blast furnace slag from iron production, and fly ash from coal-fired electricity generation. This is a development in which Australia has a strong position, led by researchers from the universities of Melbourne, Monash and Curtin, along with the CSIRO and ANSTO. And it results in up to 80% fewer carbon dioxide emissions than if we were making old-school cement by the old-school method. If we converted all cement production globally we would wipe about 1.3 billion tonnes of CO^2 off the ledger.

Here's another example: autonomous vehicles, or self-driving cars. What are the implications of automation? Some say, all good. Streets can be narrower because smart cars don't need the same margins as stupid humans. Gridlock disappears because cars just swim together like a school of fish. And emissions fall because each car takes the most efficient path to its goal, and doesn't over-rev the engine on the way.

All up, McKinsey Corporation estimates that autonomous vehicles could contribute a 15% reduction in emissions by 2025. Not bad, considering that the transport sector accounts for 90 million tonnes of greenhouse gas emissions in Australia per year, and is one of the fastest-growing sources of our emissions. But hang on, can we bank those savings just yet?

Say you own a self-driving car. You're off to a meeting downtown, where the parking is extremely expensive. Do you park the car, or just tell it to drive round and round the block on its own until your meeting is over?

Say you're a couple with schoolkids. Do you carpool in the mornings like you used to? Or do you now send the car out on three independent trips – one for mum, one for dad, one for the kids? Probably the latter. And if we do this in increasing numbers as self-driving cars come on to the market, our congestion problem could get a whole lot worse.

I'm not suggesting we should stand in the way of this progress, because the cars will just find a way to drive around us. There are more than enough human inventors and investors to propel them. What I am saying is that we can't wait for incremental change to sort the problems out. We should be thinking about a whole new transport and urban planning model to maximise the energy productivity gains that are there to be made.

Imagine Sydney reconfigured with billions of roadside sensors into a single, networked and ultra-efficient grid where autonomous vehicles talk to each other and to the traffic-control operating system. Sydney, in which the ownership model has been reimagined so that all vehicles belong to fleet operators who guarantee the rapid allocation of the next available vehicle. We cut the number of needless trips. We cut the number of cars on the road. In time, we cut the number of cars that we manufacture and ship.

> ***"Crack clean, cheap energy and you shoot to the Space Age. To get there, we need energy. Energy drives progress, progress delivers more energy."***

In short, with examples such as geopolymer cement and a reimagined vehicle fleet we run up the slope of progress, fast, hard and with better energy productivity. That's how we make an Australia that values its energy – and through availability of energy, an Australia that achieves the progress its citizens want.

Building capability

As Chief Scientist I want to make my best possible contribution. In part, it's about driving people up the slopes, by pointing out how good the view will be from the top. But I don't expect to push the country up mountains by the force of my enthusiasm alone. I expect that Australians will make their own way along a national path that is achievable, explainable and desirable. This is the second half of my role – to help find that optimum path and make sure we have the wherewithal to take it.

Energy is already identified as one of our nine National Science and Research Priorities. The Australian Government invests about $190 million towards this goal each year, plus additional investment through university block grants and R&D tax incentives. But is it enough? Can it be used to greater effect? The priorities force the question. Our challenge is to respond effectively.

As Chief Scientist I will also be pursuing two projects of particular interest to you. The first is my role at Innovation and Science Australia to help lead the development of a 15-year plan for investment in science, research and innovation. What's in it? Well, we haven't started. But you would be very surprised if energy productivity doesn't end up part of the mix. Just as I would be very surprised if you were not active contributors. If we get it right, the Government will adopt our recommendations and optimise the conditions for bold investment.

The second project I am leading is the mapping of Australia's long-term research infrastructure needs. The big, national-scale equipment that underpins our advanced research capabilities. National-scale collaborative research is something like the scientist's Olympic Games, the field where we push ourselves to be our absolute best in ways that markets and business-as-usual don't allow. And so it is one of the best places to look for the transformational science and innovation that we need.

PHOTO: IMAGEINK studio

A fortnight ago I was in Parliament House for the announcement of the first detection of gravitational waves. It was an extraordinary feat of ingenuity that simultaneously confirmed Einstein's theory of relativity, and opened a whole new way of observing the cosmos. The fluctuations in space itself, which scientists measured for the very first time, are tiny – about 1000 times smaller than a proton. In this case, they arose from two black holes colliding 1.3 billion years ago, when the only life forms on Earth were microscopic. Einstein himself did not believe that human beings could ever produce scientific instruments with the sensitivity to listen in on the universe in this way. So to prove Einstein right about general relativity, we had to prove him wrong about the limits of human ability.

In the world of Big Science, the imperative for breakthrough solutions is clear – which drives incredible people to get down to the business of finding them. That benefits all of us. The knowledge discovered through the use of the national-scale research infrastructure spurs a new wave of innovation in turn.

To name just one, the Australian Synchrotron's work in lightweight materials for transport. We have known for years that magnesium alloys can be just as strong as aluminium, but significantly lighter. The problem is their tendency to corrode. Late last year, a research team using the synchrotron announced the development of a new magnesium-lithium alloy, the first of its kind to prove immune to corrosion. It is half the weight of aluminium and a major step to the goal of economical stainless magnesium for aircraft and cars. This weight reduction will reduce transport energy consumption and reduce emissions.

The national-scale research infrastructure roadmap that I will be leading is our chance to make sure we can keep pursuing opportunities like these. To generate big ideas and get them to the market. At scale.

Scaling the mountain

This is the challenge that makes my job worth doing. But as I say, I'm only one mountaineer. So my challenge to you today is to tackle the slopes head-on. Keep the goal for energy productivity bold and visible. Ensure that it drives total emissions reductions. And develop KPIs that hold us to account for doing so.

Energy for progress, progress for energy. We are taking control of an incredible story of human ingenuity. Let's emerge from this conference with the enthusiasm to aim high – and the endurance to get up the slope.

5. Planting the Seeds of Citizen Science

February 8 2018 | Speech to the Australian Citizen Science Conference

My own participation with citizen science is limited to the time in 2016 when Elizabeth and I went swimming with the whale sharks in Ningaloo Reef. Through an innovative program developed by researcher Brad Norman, we were able to upload photos of their spots and stripes to a site that uses algorithms developed by NASA to reveal star patterns in images captured by the Hubble space telescope, modified to aid in identifying these gigantic fish and mapping their migration patterns. Citizen science has entered a new era, where technology once found only in high-end laboratories is now affordable and available to buy online, or build yourself with a 3D printer and downloadable plans. Interest in the environment is sparking low-tech versions of citizen science, such as a Canadian project in which people collect plastic debris from waterways using a plastic bottle and nylon tights. With the right settings, citizen science makes an important contribution.

Let me start with an impossible to answer question. Who invented citizen science? It depends who you ask. The birdwatchers say that it began with the Audubon Society and the great Christmas Bird Count, in 1900. The weather-watchers say that it began with Thomas Jefferson – yes, US President Thomas Jefferson. Legend has it that in 1776 he went to Philadelphia to sign the American Declaration of Independence. Then he popped into the hardware store and picked up a barometer to take back home. He thought it would be fun if he and his Founding Father mates across the country made weather observations and shared their notes. It was the birth of the National Weather Service that exists to this day. As for the historians… well, they say that all science used to be citizen science. It was professional science that had to be invented.

As Chief Scientist, I have to be neutral, so I refuse to tell you who was first. But I do know that Australia has played an important role. We have a long history of great citizen science. And we ought to hear more about it. So let me tell you just one of our stories, a story that begins right here, in Adelaide.

* * *

In the year 1847, there was a man named Ferdinand Mueller. He was born in Germany, but he'd come to Adelaide, with a dream. He wanted to be a botanist, the best and boldest botanist in all the world. And so he would collect specimens of every plant in Australia. Every plant in Australia. Off he went, marching on expeditions all around South Australia, from Queensland to Victoria, up mountains and across the deserts, for the better part of a decade. He demonstrated beyond any doubt that Australia was very large and had a lot of plants.

And then inspiration dawned. He realised that the way to collect plants wasn't to walk around collecting plants, but to sit very comfortably in Melbourne, collecting collectors. And that's what he did. He put advertisements in the newspapers calling for volunteers. And he set up a network of amateur collectors – yes, citizen scientists – all over the continent.

Over the next 40 years, more than 1300 people would contribute to Mueller's research. That includes more than 200 women, and 20 young girls, the youngest just six years old when she collected her first plant.

One of the women was Mary Kennedy. Imagine her life. She lived on a sheep station in Wilcannia on the Darling River in New South Wales, about as far inland as you could go without falling off the map. She was the mother of 11 children. And she collected more than 500 plants for Ferdinand Mueller. Mrs Kennedy didn't just collect the leaves and seeds and flowers. She asked the local Indigenous people for the names of these plants, and their uses. So she left a legacy not just for botanists, but for everyone who cherishes our Indigenous heritage. And Mueller gave her a legacy in exchange. He named a species of grevillea in her honour: *Grevillea kennedyana*.

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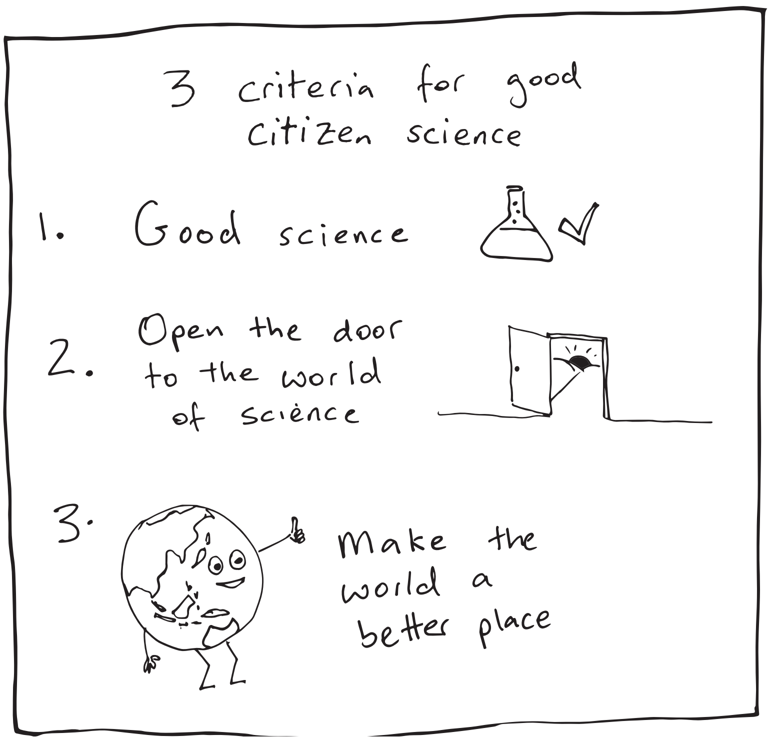
Now, in those days they didn't call it citizen science. But in hindsight, that's exactly what it was. It checks off my big three criteria for any great citizen science endeavour.



Number one, it has to be good science. This wasn't about tripping through the fields collecting flowers. Ferdinand Mueller stressed that point time and time again. He was a world-famous botanist – yes, he said that all that time, too. But it was true, and he was proud of it. And he wasn't about to put up shoddy work for the learned academics in London and Paris and Hamburg and Boston to rip apart. He needed good data. So he told his collectors the scientific goal. He explained how their contribution would assist. And to ensure that they did it properly, he sent out envelopes suitable for collecting the samples, along with a little book of instructions, with helpful diagrams.

So when a woman on a sheep station picked up her basket and headed off into the scrub, she did so in the name of science. Yes, she enjoyed the outing. But it was a package deal, fun and science. When she put samples on the mantelpiece to dry, that was science. When she carefully packaged them as per the instructions in the envelope, with details on the date and place of collection, that was science.

So number one, citizen science has to be good science, consistent with the rigorous standards we apply to every other experimental process.

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Second rule, citizen science has to be a door to the world of science. Now Ferdinand Mueller wasn't particularly interested in social policy. He was an opportunist, plain and simple. He recruited kids because they were enthusiastic and happy to wade through mud.
He recruited women because he saw their talent going to waste. In colonial times, they couldn't go to university. They couldn't enter the professions. But his project offered a glimpse of a world they longed to enter, a world where, in a different time, they would undoubtedly have thrived. They proved they were worthy of far more – full and equal access with men, on merit.

Times have changed, and very much for the better, thanks in large part to those female pioneers. But we still need those doors to science in the community. We need to make them so bright, so bold and so compelling that everyone wants to walk through. And everyone who enters feels a magnetic attraction to stay. Even if they gave up science in high school. Especially if they gave up science in high school! The future belongs to all of us. The science that will shape it ought to be shared as well.

“We often focus on the ‘science’ part of citizen science. But the ‘citizen’ is important as well. It reminds us that we are part of something greater than ourselves. And I think it spurs us to be part of making something better for the generations to come.”

So number two, citizen science has to be a door to the world of science.

* * *

And number three, it has to make the world a better place. In the end, that's what makes it worth doing.

It's all there in the letters that were written to Mueller, more than 150 years ago. Time and time again, these farmers' wives and stockmen's daughters spoke of their pride in doing something for Australia.

Remember the context. It's the 1800s. It's the era of Banjo Paterson and Henry Lawson. We're falling in love with our country. There's even talk of federation in the newspapers. And here's a project that unites men and women from every colony, with a mighty vision, and a love of country.

We often focus on the 'science' part of citizen science. But the 'citizen' is important as well. It reminds us that we are part of something greater than ourselves. And I think it spurs us to be part of making something better for the generations to come.

So there's my three criteria of citizen science. It has to be good science. It has to be a door to science. And it has to make the world a better place. A project that ticks all three boxes will inspire talented people to succeed.

* * *

Now, if we could go back in time, pick up Ferdinand Mueller in 1847, and drop him off at this conference he'd probably collapse in shock. But he'd get over it. And he would ask the question at the heart of this conference, what's next for citizen science? In the 21st century, what role will it play in the human quest for knowledge? What place will it take in people's lives?

You can imagine two scenarios.

The first is that citizen science will be left in the 20th century. Robots and artificial intelligence will do more and more of the tasks that in the past could only be done by large numbers of humans. For example, examining images from space telescopes.

NASA is already using neural networks to trawl through a database of images from 150,000 stars to catch the minuscule change in brightness that signals the presence of a planet. Automated systems have been used before, but it's machine learning that's changing the game. Now the machines are winning.

And in the same way, some people will tell you, all citizen scientists will be made redundant. And then all scientists. And then perhaps all humans. Citizen science will be something we do for fun, not something we do because it makes a meaningful contribution.
That's scenario one.

The second scenario accepts that technology is changing, and so citizen science is changing as well. But it's changing for the better. It's surging in the slipstream of technology, not falling behind. On this reading, citizen science has never been more important, or alive.

That's the position of *The Economist* magazine – and say what you like about *The Economist*, it's not known for sentimentality. *The Economist* calls the current moment "punk science", brilliant technology plus resourceful humans.

At one end of the spectrum, you have tools that used to belong in high-end laboratories, such as fluorescence microscopes costing many tens of thousands of dollars. Now with a 3D printer from Aldi and downloadable plans from the University of Sussex you can make a fluorescence microscope to occupy pride of place in your home for less than $500. You can order a gene-editing kit online for a few hundred dollars. You, the citizen, can do so much more – thanks to technology.

At the other end of the spectrum, people are still pretty good at knocking up low-tech tools. There's a project in Canada monitoring small plastic debris on the surface of the water. When scientists collect this plastic debris they use special nets that cost $5000 dollars.
In the citizen-science version, it's done with $10 toddler's tights. Grab a plastic bottle as the mouth, slip over the tights, attach it to a boat, and there you go, a DIY surface skimmer.
But now scientists and citizens are sharing these ideas, in the way that foodies share pictures of smashed avocado on Instagram.

It’s a revolution dubbed “open-source hardware” by analogy with the “open-source software” revolution that has dominated both amateur and professional software development for more than 20 years. A good idea goes so much further, again, thanks to technology.

I find scenario two far more compelling. But here’s the thing. It takes work. It takes vision. It takes creativity. It takes strategy. And it takes leadership. Above all, it needs you.

Everything I know about human beings tells me that the golden age of citizen science is still ahead. And we’ve come to Adelaide today because we agree. One hundred and seventy years ago, a man named Ferdinand Mueller came to Adelaide with a dream. Our mission today is to continue to live the dream.

CHAPTER 02

Engaging Students in STEM

“Humanity’s superheros”

Chapter 2 | Engaging Students in STEM

Introduction

There is nothing crueller to children than a culture of low expectations, and there is nothing more likely to produce mediocrity than aiming for it.

Children are enormously plastic in their learning and the job of the education system is to help them develop muscle memory through deep learning in core subjects. The aim should not be to produce generalists but to give children the grounding that will allow them to become experts, to aim high and to know their subject deeply. This means specialist teachers, detailed teaching of the fundamentals and specific entry requirements for university.

As Chief Scientist, I combined with the Australian Mathematical Sciences Institute to analyse university prerequisites in 2020, an analysis that showed the extent to which universities have moved away from mandated requirements. Only 19 of the 1587 courses we looked at, in the disciplines of architecture, computer science, economics and commerce, education, engineering, health and medical science, and science required advanced mathematics. I have not advocated a return to prerequisites – there are good equity and other reasons to retain flexibility – but I have worked with vice-chancellors to advocate for a consistent set of clear advice to students on the subjects they should be studying at school to set them up for success, under the banner of Australian Informed Choices.

This series of speeches tackles my enduring preoccupation with the fitness of the education system to train the people Australia needs to be a world leader in new industries, innovations and discoveries.

6. Raising 21st Century Citizens

July 10 2018 | Speech to the CONASTA conference for science teachers

> Paul from the science fiction novel Dune is curious, flexible, agile and collaborative not because he took classes on how to be curious, flexible, agile and collaborative, but because he studied his discipline and mastered content. Paul is fiction's version of Silicon Valley's "T-shaped worker", a worker with deep expertise in a specialist subject (the vertical bar in the T) and generalist skills such as communication and critical thinking (the horizontal bar in the T). That deep knowledge and intense training is what allows workers to branch out creatively in the workplace, to solve big problems and to make breakthroughs. When I employed engineers and scientists at my company in Silicon Valley, we hired T-shaped workers. I had no interest in friendly dashes or lonely I's. Unhappily, an idea has taken hold in parts of our school system that actually knowing things is outdated; that all students need to learn is 21st century skills. I liken that idea to training a young person to become a concert pianist by helping them to master music theory but without requiring that they practise.

A few weeks ago I was interviewed for a podcast. The journalist asked me what I expected to see in the classrooms of 2030. I said the first two words that popped into my head: human teachers. So I expect to see you all back here at CONASTA 2030. And I'll put up my hand right now to appear on the program, even if I have to appear by hologram.

This event has a special place in my heart. CONASTA was one of the first forums I addressed as Australia's Chief Scientist, back in 2016. I set out my goals, and I asked you to hold me accountable. Well, we're two years in. I've seen many encouraging developments, and they're worth acknowledging.

Who would have thought that the Minister for Education could come to CONASTA, and say what he said yesterday, and I quote, "There just aren't enough STEM-trained teachers in our classrooms." And then see that speech reported in every outlet from the Daily Telegraph to the ABC? He touched a nerve. People care. And that confirms my impression that momentum is growing, in a good way.

But I've also seen something else in these two years, something that I worry might derail our progress, or cloud the path. There's a growing sense of confusion about what we actually mean when we speak of a "21st century education".

> ***"I can't explain why so many well-meaning people associate being a 21st century worker with knowing less and talking more"***

I say "students should be work-capable", and people hear "we need to teach generic skills like collaboration, instead of content knowledge like chemistry". I say "engage children through real-world problems", and people hear "great, let's toss out the textbooks". I say "children should develop the passion to learn", and people hear "let's leave it up to the children to decide what they want to be taught".

I can't explain why so many well-meaning people associate being a 21st century worker with knowing less and talking more. But clearly, the onus is on me to explain what I do mean, and make the case for it. So today I want to use my time to do two things.

First, I want to talk about why, in 2018, there is still a fundamental duty to teach students content – concepts, facts and principles. Taught by teachers trained as experts in that content, with all the status and resources and professional development that we would demand in any other expert occupation. Then second, I want to give you an update on progress towards the goal of a better education, a real 21st century education, for all our children.

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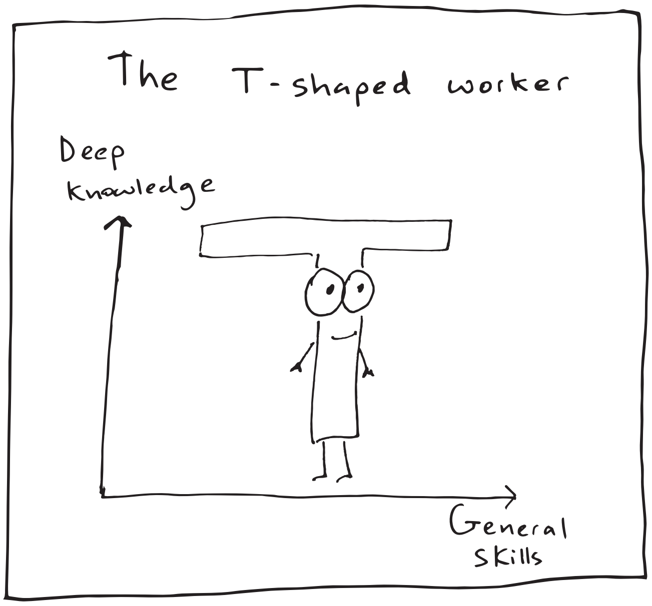
Let's begin with the importance of teaching content that genuinely challenges the student. And if you'll forgive me, I'm going to lead into my argument via the book we could call *The Sacred Text*. I mean, of course, the best-selling most highly acclaimed science-fiction novel of all time, Frank Herbert's *Dune*.

If I can't quote science fiction to science nerds – and we're all science nerds here – then I'll never get the opportunity. So I'm taking it now. But I promise, it's relevant.

So, about *Dune*. It's a very thick novel published in 1963. It is well worth reading, but don't watch the movie. Let me repeat. Do. Not. Watch. The. Movie. You don't need to know anything about the plot, but I want to introduce you to the hero: a young man named Paul, an exile on a desert planet, trying to wrestle back control of a galactic empire.

One of the first things you learn about Paul is that he has a remarkable capacity for adapting to new environments and mastering new skills. But the next thing you learn is that this capacity wasn't born in him. It was instilled into him. He'd be taught a principle. He'd practise it, again and again and again. He'd apply it in a real-world context. And then in moments of high stress – no, not a NAPLAN exam, think digging your own mother out of quicksand – Paul thinks back to the lesson. He thanks his teacher. He applies the content creatively. And his mum survives.

Page after page, we see Paul learning. He's curious and flexible and agile and collaborative, not because he attended classes on how to be curious, flexible, agile and collaborative, but because he developed those skills in the context of mastering content. Principle. Practice. Application. Principle. Practice. Application. That's the lesson of *Dune*.



I didn't grasp that lesson when I first read *Dune* as a teenage boy, but I realise now that Frank Herbert was describing a concept that IBM would later crystallise as the "T-shaped worker". The vertical line of the T stands for deep expertise in a discipline. You have to acquire that first. The horizontal bar stands for your flexibility to apply that expertise creatively, as part of a team in a workplace, and to develop new skills as opportunities present. That comes second.

Think of it like a garden trellis. Your subject, or discipline, gives you structure while you grow. Then you have the capacity to branch out. Without the trellis, you're just ground cover, sprawling out in all directions, no matter how good the soil or how much love your parents pour in. And it turns out that people with trellises, T-shapes, are remarkably well-adapted to planet Earth.

I think of the current CEO of Google, Sundar Pichai. He was born in rural India. His family didn't own a telephone until he was 12. So needless to say, no iPad, no smartphone and no laptop. His first degree was metallurgy. His masters was in semiconductor physics. Then he joined Google. He developed the Chrome web browser that you probably use every day. When he was appointed to his first senior role he was praised by Google founder Larry Page for – wait for it – his deep technical expertise, combined with "tremendous entrepreneurial flair". He's said to be incredibly quick with calculations with a near-perfect memory for statistics. He climbed high, on a trellis.

Or how about the leader ranked last year by *Forbes* magazine as the most powerful woman in the world, German Chancellor Angela Merkel. She studied physics at university because she did poorly in a physics course in high school and refused to be beaten. She went on to earn a doctorate in quantum chemistry. Her political success is often attributed to her capacity to approach problems methodically, combined with a brain described by German media as a "machine for learning".

One more example: Jeff Bezos, the CEO of Amazon and the richest person in the world. He describes the ideal worker as an "expert with a beginner's mind." And he specifies that by "expert", he means "domain expert", who has mastered the content so thoroughly that she can play with it.

So, building web browsers, leading Germany, running a global corporate empire or tackling giant sand worms on a desert planet whilst saving the galaxy – it starts with learning content, and mastering a discipline.

Now it could be argued that all these leaders were the rarest of the rare – people who would work out how to succeed no matter what. So let's look at the evidence from run-of-the-mill Australian workplaces employing bang-in-the-middle-of-the-bell-curve people.

I have had many, many meetings with employers, in my role as Chief Scientist and as Deputy Chair of Innovation and Science Australia; and before that, as Chancellor of Monash University and President of the Australian Academy of Technology and Engineering; and before that, as the CEO of a publicly listed company. In all my meetings with people actually hiring graduates, no-one has ever said to me, gosh, we don't have enough people who know how to collaborate. No, what they say to me is, we don't have enough specialists in software engineering. We can't find graduates who are fluent in maths. We have meetings where three-quarters of the people in the room can't critique a set of numbers without pulling out a calculator and slowing us down. They were asking for T-shapes, and getting flat lines – but the flat line wasn't lifted up and anchored by that all-important vertical pillar.

So I was deeply interested to read a report released last month by the New South Wales Department of Education, prepared by a team led by Professor John Buchanan from the Business School of the University of Sydney. Professor Buchanan was commissioned to investigate what today's kindergarten children will actually need in order to thrive in the 21st century, not just in work, but in life. What he found was a widespread preoccupation with the so-called "soft" or "generic employability" skills, coupled with a belief that actually knowing things was outdated. But the evidence from every field of knowledge he drew on – cognitive psychology, education, philosophy, engineering, applied labour economics – said very clearly: give up content at your peril. I strongly agree.

> ***"It seems to me that the cruellest thing we can do to school students is take away the trellis of structured subject content, and with it, that deep-rooted conviction that they are capable of learning and contributing"***

To be clear, Professor Buchanan acknowledges that future workers – or let's say, future adults – do need to develop what he calls "sound learning dispositions" – concentration, resilience, curiosity, and so forth. But to quote from his report: "We note that once learning foundations are built in early years education, such dispositions are best acquired in the context of mastering specific disciplines or fields of vocational expertise." "Generic skills only have meaning within specific domains of knowledge."

In the words of a participant in one of Professor Buchanan's workshops: "What's the use of learning to collaborate if you don't have anything distinctive to contribute?"

Indeed. It seems to me that the cruellest thing we can do to school students is take away the trellis of structured subject content, and with it, that deep-rooted conviction that they are capable of learning and contributing. But if we want a content-rich curriculum then we need teachers who are experts in that content.

* * *

I'm going to return here to *Dune*. Remember Paul, the T-shaped ahead-of-his-time, save-the-galaxy hero? We are constantly reminded of the excellence of his education. He was trained by a master swordsman. A master musician. A master of mathematics and computation. And his mother: a master of warfare, politics, history, philosophy, chemistry, biology, and more. The point is that they were all subject matter experts, as well as gifted teachers. Why was that important? First, because they knew what they were talking about. And they explained it to Paul in structured lessons. Second, because they set the challenge at a high but achievable level. And third, because they rigorously monitored Paul's performance and reported to his parents.

I smiled when I saw that these were exactly the same three characteristics that the winners of last year's Commonwealth Bank Teaching Awards had in common: explicit instruction; high expectations; effective use of performance data.

I want to single out that second characteristic, high expectations. Wouldn't it be luvverly if children just woke up, on Monday morning, with a voice inside telling them that their true calling in life is organic chemistry. But we don't awake spontaneously to a knowledge of our talents and passions. We develop them by mastering the foundations, and that means sticking with it. Your passion, as teachers, is the glue.

It's particularly important to inspire children towards mathematics. Mathematics is the language of science. And none of us arrive in school at the age of five as native maths speakers. We only gain fluency by learning things in sequence. And there is no substitute for the precious years of learning mathematics, in sequence, in school. We know this because we keep trying to find one.

We allowed universities to remove the mathematics prerequisites from courses that really do need a strong grasp of maths – for example, science. At the same time, we allowed students to enter Year 11 in the belief that choosing advanced mathematics would hurt their ATAR. That's how we ended up with a large cohort of students arriving at university and signing on for maths-intensive degrees without the foundations to last beyond their first semester.

We have evidence, including data reported this year, that students who study foundation maths in school, rather than intermediate or advanced maths, are twice as likely to fail first year university biology and chemistry.

But this insight isn't new. In 2009, a study conducted at Western Sydney University looked at the performance of HSC graduates in first-year university mathematics. One hundred percent of the students who entered university with advanced maths passed; 77% of the students entered with foundation maths failed. I repeat, fewer than one in four of the students with a background in foundation maths passed the first-year university maths course. Some might struggle through with bridging courses, but the same study concluded that a short bridging course is an inadequate solution to the problem.

So we've known this, not just by anecdote but there in the data, for at least a decade. And we've still allowed cohort after cohort of students to pay the price. It's not just the price of dropping out, although that's bad enough, mentally and financially. It might be even worse to scrape through, and then find that you can't compete for a job.

When I was a CEO employing IT graduates, we would look at their academic records. That got them through to an interview. But we would also put the candidates through a pressure test, such as a three-hour programming task. Not surprisingly, a certificate from a university that showed they scraped through was not enough to steer them through the test. We were looking for people like Paul: masters of their subject with the capacity to thrive in stressful situations. I read their resumes. The Pauls we discovered left their high schools prepared.

Some university entrance course guides currently suggest that mathematics should be considered "assumed knowledge". I've always wondered what that would mean to a Year 10 student. So I looked it up on a Group of Eight university website. This is what I discovered:

Assumed knowledge is not a requirement in order to apply, but helpful to have a background in the courses you'll be studying. If there is assumed knowledge that you don't have, you might like to consider doing some extra study, or even your own research to get up to speed.

You "might like to consider" it? Are we seriously suggesting that you can pick up calculus in your spare time without an expert teacher to guide you? Assuming you feel like it? The time to ask and expect bold things from students is not at the end of the school education process, but from primary school. But if we ask for high standards from students we need to ask it of people who make the decision to be teachers, and we need to support those teachers as the expert professionals they are.

"The time to ask and expect bold things from students is not at the end of the school education process, but from primary school"

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So now let me turn to the progress of the past two years. I'll start with the good.

Number one, we have opened the STAR Portal. Hands up any one in the audience who hasn't visited our website for extra-curricular science programs. That's your homework. Everyone else, spread the word. It's a portal to a world of inspiration.

Number two, we have delivered the STEM Industry Partnerships Forum report. It was handed to Commonwealth, state and territory Education Ministers in April this year. I was privileged to be the forum Chair.

The mission we were given was to think more strategically about the role that employers can play in school education. It was not a hostile takeover of schools by companies. Every employer we spoke to was very clear that the responsibility lay with government, principals and schools. Their objective was to help.

But they were used to thinking like businesses, seeing their investments lined up against the outcomes. That's how you develop a new business line – pilot, evaluate, optimise, scale. When you're a business and you put money into schools, how do you know if you're actually helping? The answer is that you need academic researchers to follow the outcomes.

But the researchers cannot do that without access to de-identified student data that transcends state and sector borders. But that data is not available because we do not have a national unique student identifier – one of the recommendations in the STEM Partnerships Forum report.

Many of you here today would have first-hand experience of industry-sponsored programs that work, so we know they exist. But we can do more. We can get more businesses involved, and those who are involved can boost their impact, with better data and more visibility of good programs that others can learn from. We've put those recommendations to the Ministers, and in the meantime, we've got people in industry thinking about what more they can do.

Number three, we have seen, at long last, some signs of positive movement on the ATAR and prerequisites. Recommendation 2 of the STEM Industry Partnerships Forum report says:

Review how the ATAR can incentivise students to study the most advanced and appropriate subjects, and the impact of universities having dropped prerequisites for courses that require a strong foundation in mathematics.

When we included that recommendation I thought it might attract some comment. It ended up on the front page of the *Sydney Morning Herald*. So I am not alone in my concern that we are sending the wrong signals to students, to parents and to principals. You, our science teachers, know better.

Now the federal Minister for Education has said very clearly: "All Australian universities should reintroduce clear prerequisites as part of their admissions processes, particularly requiring maths or science subjects, as well as English." And the sector is listening.

The Council of Deans of Science has commissioned ACER, the Australian Council for Educational Research, to look at the relationship between the mathematics studied at high school and performance at university, so that the evidence can be put directly to the decision-makers. The New South Wales Education Standards Authority is working with universities to investigate the perceptions and reality of ATAR gaming with lower level maths. Western Australia has already taken steps to boost the recognition of advanced maths in the calculation of ATARs. And the Australian National University has announced that from 2022, if you want an undergraduate place, in any discipline, then you have to study both English and maths. We've got a long way to go, but at long last, this is real momentum. Let's keep up the pressure.

* * *

Which brings me to the unfinished business. Yesterday, Minister [for Education and Training Simon] Birmingham laid it out in the starkest terms. He said very clearly, and I will repeat it, because we ought to remember it: "It is unacceptable that secondary school students are taught science or maths subjects by people without specialist skills in science and maths."

The Minister has defined a new aspiration: every high school should have access to specialist teachers to teach science and maths subjects. And we should strive to achieve this within the next five to 10 years.

The aspiration comes with expectations, on state and territory governments and universities. In welcoming that aspiration, I hope that we will not just focus on initial teacher training – as important as it is. In-service professional learning is critical, too – a lesson I am urging politicians to learn from the STEM Partnerships Forum report.

Recommendation 3 states:

Develop minimum national requirements for teacher professional learning, a proportion of which should include relevant, discipline specific professional learning, that must be satisfied in order to retain ongoing registration as a primary or secondary teacher.

Recommendation 4 says:

Support principals and lead teachers to develop and implement high quality professional learning materials and teaching practices in mathematics, science and technology.

I recognise that it is not fair, reasonable or realistic to impose a raft of new requirements on teachers that schools simply lack the resources to meet. But nor is it fair, reasonable or realistic to expect the system to change by itself.

You, of all people, know that in life as in stoichiometry, the equation has to balance – inputs to outputs. How do you optimise a chemical reaction? You find the right catalysts. In the stoichiometry of education, there are many potential catalysts, from the curriculum, to teacher training, to school leadership, to workforce planning and class sizes. But we have to find them and deploy them like chemical engineers, with evidence, with strategy and most of all, with clarity of purpose. Putting requirements on universities and education authorities is a way of sending the signal. This has to be a priority.

You are the expert teachers who can see the future and are already striving to lead the change. It is time for Australia to recognise that contribution, resource that contribution, and extend that contribution. We must ensure that our students are taught to master content, lots of it. We must ensure that all specialist teacher are subject-matter specialists. We must restore the relationship between universities and schools through prerequisites that send signals to principals, teachers, parents and students. We should make data on outcomes available for the benefit of students and for impact research. And finally, we must clarify the role and operation of the ATAR so that it does not inadvertently send the wrong signals.

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I began with my one certainty for the classrooms of 2030. Human teachers. Let me finish with a challenge to everyone here today.

You are our science teachers. You are specialists in the two halves of the future – the future adults, and the future technologies. Artificial intelligence. Gene editing. New sources of energy. So much more. You see the humans in front of you and the technology already entering the classroom, continuing to evolve together. So you are the Ambassador of the Future in your school.

I hope you will embrace that role, and challenge your students to think about the sort of society we want to be. And I hope you will keep making the case in your schools, and to your colleagues, for nurturing those T-shapes – if you need to, by reference to *Dune*. If you remember nothing else, take away that lesson: heroes learn hard content from fabulous teachers. Oh, and Never. Watch. The. Movie.

May the Force be with you.

7. Measuring Up

November 9 2016 | Keynote Address to the Mathematics Education Research Group of Australasia (MERGA) 40th Anniversary Conference

My shortened version of Auguste Comte's "hierarchy of the sciences" is that in the beginning there was mathematics, and mathematics begat physics, which begat chemistry, which begat biology and so it goes. Mathematics is critical – for virtually every invention in recorded history and every transaction in the modern world. Mathematics is the language of science and progress. It is how you gather evidence. But maths is hard. Which is why it must be compulsory in schools and taught by specialist teachers who can make it compelling. It's too late to pick it up at university. Through maths, students learn the pay-off of persistence. I have been concerned about the drop-off in advanced mathematics in the final years of secondary school and have encouraged a redoubled effort. This is one purpose of my Australian Informed Choices project in partnership with thought-leading universities, which are now working to develop much clearer signals to school students about the subjects they should choose at school – subjects that will set them up for success at university and in other post-school settings. And what finer role model can there be than Florence Nightingale, the Lady with the Lamp?

Your 40th conference. A number to celebrate. And not just for conferences. There are 40 squares on a Monopoly board. Forty in Italian is quaranta – and 40 days was the duration that ships were forced to wait in harbour in the time of the Bubonic Plague to stop the spread of infection. It was the original quarantine. It took 40 attempts to develop the answer to most of life's sticky problems: WD 40. Or, to give it its full name, Water Displacement, 40th formula. And 40 is the highest number that Sesame Street counting has ever reached. So there you have it – it's a milestone, whether you're a Muppet or a mathematician.

I'm marking a milestone of my own tonight: my first formal event since taking off my hat as Australia's Chief Electrician, and resuming my hat as Australia's Chief Scientist. It also gives me the opportunity to tick off another big item on my bucket list.

I'm at a gathering of maths education researchers. And I'm going to begin with a pop quiz. No calculators, no smartphones allowed! Pencils ready. Who am I?

- I was born in 1820 into a wealthy and well-connected British family.
- As a child, my hobby was building statistical tables, in which I captured trends in the vegetable output from our garden.
- At my request, I was tutored in mathematics for two hours every day.
- I became a maths tutor myself, before applying for a position as a Superintendent in the British military.
- I was deployed to the battlefront, where I collected extensive data on soldier mortality rates.
- This formed the basis of an 850-page report that I published in 1858, saving countless thousands of lives by prompting major reforms in hospital practice.
- I helped to establish the International Statistical Congress and served as a data consultant to the US Army in the American Civil War.
- I also invented the polar area diagram and pioneered the infographic.
- I was elected to the Royal Statistical Society – and here's a big clue – becoming the first female member at the age of 38.
- I died a legend amongst statisticians in 1910.


Florence Nightingale
Creator: London Stereoscopic Company
CREDIT: Getty Images

I am, of course, Florence Nightingale, mathematician. Yes, Florence Nightingale, the Lady with the Lamp. It ought to be the Lady with the Logarithm. She saved far more lives by her grasp of numbers than by her gift for nursing. And she put data at the heart of healthcare as we know it today.

So throw out your textbooks, I'm correcting the record.
Florence Nightingale is henceforth the patron saint of mathematics. And I'm paying my personal tribute by drawing out four lessons from her story for maths educators today.

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Lesson one, maths is critical. Over the past few months I've asked audiences to imagine the world without electricity. You have to step back 200 years. No electricity, but technology and sophistication were in abundant supply, with, for example, Britain benefitting from steam trains and the House of Lords. It was already a life you could imagine.

> ***"There is nothing so disempowering as ignorance of the numbers we need to navigate the world"***

But what if we lived in a world without mathematics? You have to cast your mind back more than 5000 years, to a world barely crawling from the Stone Age. Take away numbers, and you take away commerce, farming, medicine, music, architecture, cartography, cooking, sport, and every other activity we've invented since 3000 BC.

The first thing you looked at today was probably the time. The second was probably the temperature. The third was perhaps your hotel bill. There is nothing so disempowering as ignorance of the numbers we need to navigate the world. Never forget, the weakest person in a negotiation is always the person who can't add up in their head.

If I had my way, we would go back in time and reverse the letters in STEM. Maths first – maths as the language of science. Maths as the language of progress. Maths as the prerequisite for learning, and for life. But maybe I wouldn't stop there. Maybe I would abandon the acronym entirely. I consulted on this point with a Year 12 student on a work experience placement in my office last week. She tells me that, amongst students, it's still just as it was – science and maths. STEM had never been mentioned in school. Science and maths, they're still good words. But let me continue.

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Lesson two, learning maths is hard. It is hard in the sense that it demands our early persistence. Learning in maths is a continuum, always building the next lesson on the skills mastered in the lessons before. To fall behind is often to stay behind. And to drop out in school is to kneecap your opportunities in later life. It is very hard to retrofit the lost lessons into students' brains after they start university, as you know all too well.

Like learning English, kids need to start maths early. And keep going. I understand the temptation in schools to lighten the content in the maths curriculum, in the dubious belief that easy things are more attractive to students, and any maths is surely better than no maths. I also understand the incentives that lead students to study maths at a level below their true ability. But a lighter load is really a heavier burden; it is the burden of low expectations.

Florence Nightingale understood this reality from an early age. She did not consider herself to be naturally gifted in maths, but she did believe she had the capacity to learn. And so she refused to settle for the level of maths education thought fitting for girls of her time. She demanded from her parents the support to raise herself to something higher, something that would make it possible to participate fully in public life. She should be our model for the education of all students, regardless of gender, postcode, cultural background or family income.

And surely, the most effective way to raise expectations in schools is to start at the endpoint of the education continuum, with universities. That is, implement maths prerequisites in all the courses that need a grasp of maths. At a stroke, we would signal to principals at primary and secondary level that they simply can't afford to drop the ball. Maths has got to be a priority for every student, from kindergarten to graduation.

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But that brings me to lesson three: compulsion is not enough. Some children seem to fall in love with maths at birth and, like Florence, are hungry to be taught. Others need help to turn an arranged marriage with maths into a genuine passion. That is the role of the teacher, to make a subject not just compulsory, but compelling.

But, of course, it is very difficult for any teacher to inspire a passion that they don't feel themselves. It is also extremely disrespectful to the profession to assume that anyone can teach maths, as long as they stay at least one lesson ahead of the students in the class. Maths teachers should, in the first instance, be experts at maths. It's that simple – and yet, it seems, that hard. In far too many schools, out-of-field teaching remains the norm, peer networks are thin, and professional development is an impossible dream.

We seem locked in a cycle of poor outcomes and diminishing expectations, passing on to each generation of students, teachers and parents the frustration we feel ourselves. Entrenched practices are hard to break and demoralising to report. But just because the problems run deep does not mean that we should shy from solving them.

> *"Maths teachers should, in the first instance, be experts at maths - it's that simple"*

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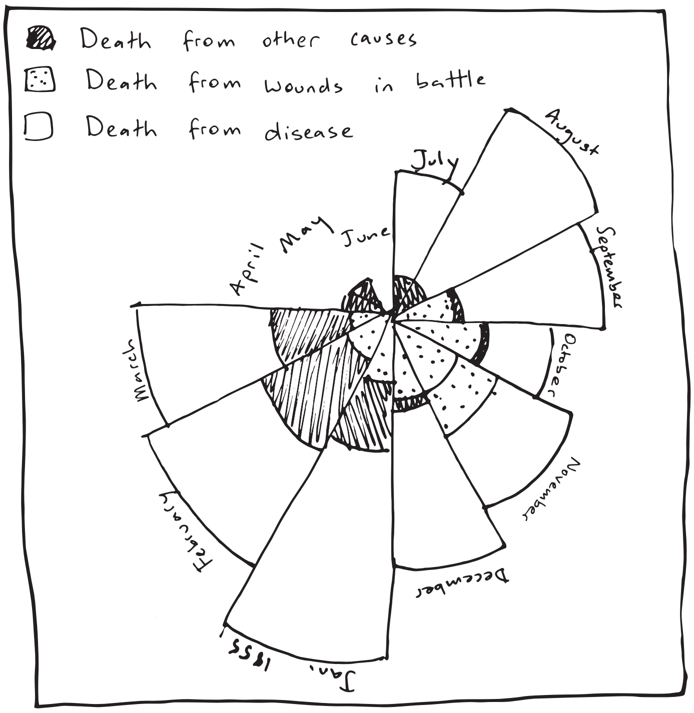
And that brings me to my final lesson from Florence: using evidence to make a difference. Imagine the situation Florence Nightingale confronted in the Crimea. Everyone knew that, in a war, soldiers get shot. Everyone knew that people who are shot tend to die.



Reproduction of the first of the two Coxcomb Charts provided by Florence Nightingale in Notes on Matters Affecting the Health, Efficiency and Hospital Administration of the British Army, 1858

What they didn't know was that the vast majority of deaths in the Crimean War weren't caused by wounds at all – they were caused by diseases like cholera and typhus. Thus military leaders didn't implement the basic sanitary precautions in field hospitals and military barracks that would save lives by stopping the spread of disease.

Florence Nightingale saw the problem, but she needed her own ammunition. So she counted the dead, collected the data, and displayed it in a polar area diagram. It was a credible, clear and compelling display of the causes of death. And suddenly the problem was no longer too abstract to ignore. It was fixable. That is how a woman – a nurse – took on the top brass of the British military and won.

Think of Florence Nightingale the next time you feel that arguing for education reform is like the Charge of the Light Brigade, riding nobly into the Valley of Death. Evidence can give decision-makers in all these communities the impetus and confidence to act.

But it can only do so if we present it in an actionable form. It cannot be just a statement of problems. It cannot be just a statement of demands. It has to be written and read as a statement of opportunities. In all my dealings with politicians, the education sector, industry and parents, I sense an enormous will to change. Your research can be the springboard they need. But the springboard has to be fabricated from evidence and solutions. And it has to be fabricated to minimise the side effects that might cause it to break.

Before I finish, let me leave the specific world of mathematics and return briefly to the broader world of maths and science, and their embodiment in engineering and technology. Two examples from my work as Chief Scientist. Some of you will know of these projects, either as participants or supporters.

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First, a project on the cusp of realisation. On my first day in the job, I was handed a thick book. It was called the STEM Program Index, or SPI Guide, and it was a list of extracurricular programs available to students through third party providers, such as firms and universities. It was a good idea and it patched a faulty connection – the link between providers and students.

But it was a patch of limited use. Being a printed book, the medium limited the message. It was time-consuming to search. It was a one-way communication with no capacity for feedback from students. Of course, it was out of date even before we hit print. And it would be very expensive to hit print again. The solution was obvious: an online portal. It would turn a temporary patch into a living two-way link. The model: TripAdvisor – or AirBnB.

The challenge: to build it, test it and resource it. Inspired by that challenge, we brought together a network of corporate sponsors – Telstra, BHP Billiton Foundation, Commonwealth Bank – and organisational backers – the Department of Industry Science and Innovation, the Australian Mathematical Sciences Institute and Engineers Australia. We gave it a new name: the STAR Portal. It's now in widespread testing and almost ready to launch. We expect to go live in late July – watch this space. And give us feedback.

* * *

The STAR Portal project opened our eyes to another opportunity: to help industry providers to be more strategic with their resources.

We have anecdotal evidence that students and firms can both benefit from well-structured and targeted programs. But we have not collected the evidence systematically or filtered it back into program development. So industry providers are constantly reinventing the wheel. Other interested parties are deterred by the fact that they simply don't know how to be effective. How could we empower them to act and channel their enthusiasm in the optimal way?

The COAG Education Council had the same concern. They called for a national STEM Partnerships Forum to find out. And the forum, which I chair, met for the first time in Parliament House in May. The first task is to take stock of the current programs and their outcomes, to be presented at our next meeting in a few months' time. We will then be able to determine whether our ingoing assumptions about industry programs are correct, and base future investments on a far more solid foundation.

Evidence in place of intuition. Florence would be proud.

Indeed, a toast to Florence Nightingale, the Lady with the Logarithm. And to MERGA as it enters its quarantesimo year. Let's remind this country there's strength in numbers. Let's commit to starting maths education early. To keeping it going. To treating our education system as a continuum. To keeping the bar of student aspiration high. To helping students clear the bar. To fighting the incumbency bias. And above all, to taking our research beyond observations, into the realm of solutions.

8. Saluting Roy Stanhope: Teacher, Leader, Legend

July 4 2016 | Roy Stanhope Oration at CONASTA 65, the 65th annual National Science Education Conference of the Australian Science Teachers Association

The performance of Australian students in mathematics is not a new issue but an increasingly pressing one, exacerbated by students' perceptions that taking easier maths courses will help them game the ATAR, a move in universities away from mandating prerequisites for entry, and the lack of specialist qualifications among the teaching cohort. This speech to science teachers argues that fixing this will not only secure Australia's economic future by ensuring we can be a leader in innovation and new industries, but is our best shot at repairing disadvantage and using the talents of every child. More than half a century ago, Roy Stanhope made a not-dissimilar observation about science. I was glad to be talking to teachers. Parents, schools and curriculum material are all important, but good teachers are the most important ingredient of all.

When Vic Dobos asked me to deliver the Roy Stanhope Oration at CONASTA 65, of course I leapt at the chance. The need for an organisation like the Australian Science Teachers Association is so obvious today that we forget just how far ahead of his time its founder really was.

We know of one research report on science teaching in schools published in this country prior to the Second World War. Just one. Roy Stanhope wrote it. But he wasn't the sort of researcher who rests content with publishing reports. He was the sort of visionary who acts on what he finds. He founded ASTA in 1943. He led the ground-breaking national survey of secondary science teachers in 1964. He pointed out that 30% of the teachers who responded to that survey had no tertiary qualifications in science. And that evidence really did hit the mark. It shifted the terms of the national debate, and helped to change the approach to teacher education. For all those decades, Roy played the long game. He never gave up the mission. He let the data make the case.

So in the tradition of Roy Stanhope, I have come to CONASTA 65 with some data of my own: a national scorecard on science and mathematics in secondary schools prepared by the staff in my office. I'm proud to launch it tonight, and I will have more to say about its contents in a few moments' time. I hope, like Roy, we can use that evidence to good effect.

But first, I tip my hat to a skilled teacher of science and a wonderful servant of our country.

Taking flight with science

Now I have never seen a comprehensive list of the inspiring figures of history who were also great teachers of science, but I suspect it would be very long. I am always stumbling into science teachers in unexpected places.

Just the other week, I had reason to inquire into the history of the hot-air balloon. And guess what, the first person to ever go up in a hot balloon was a teacher of chemistry and physics. His name was Jean-François Pilâtre de Rozier, and he made the first manned, untethered hot-air balloon flight in 1783. At first I couldn't believe it. I've spoken to a lot of school principals over the years. And I can tell you, a qualified chemistry and physics teacher isn't easy to find. You tie them down; you would never send them off in an experimental aircraft. Even at the time, the French king was extremely reluctant to let this determined young man risk his life. He wanted to put two condemned criminals in the basket instead. But de Rozier read it differently. He knew that this experiment was a risk – but he chose to redefine it as an opportunity. And in his eyes, that opportunity was a tremendous honour. He put that case to the king, and he won. And so it was that when the first balloon rose into the sky, the first flying science teacher was on board.

Ladies and gentlemen, science teachers have been superheroes for a very long time. Now I could go on to say that the first flying science teacher was also the first known fatality in an air crash, due to an unfortunate incident that took place in the following year. But why ruin a good story with an awkward sequel?

My backstory

Of course, that's the trouble with superheroes these days – the endless and appalling sequels. And when they're done with sequels, they have to have prequels, so they can ruin the story at both ends. But I won't judge, because Vic has asked me to share a bit of my own prequel today, and I'm delighted to do so.

A long time ago, in a school far away, some great teachers turned me from a curious child to a soldered-on geek. Mr Fergus, my senior chemistry teacher. Mr Noonan, my senior physics teacher. And Mrs Trend, my senior mathematics teacher and the Head of the school. There were other teachers along the way, too – teachers who made science and mathematics a rich and wonderful part of growing up.

Today I look back at the science-fiction stories and comic books of my childhood, and I still think they're fantastic. Back then, we thought the things their authors imagined were too fantastic to ever be real. Today, we think the authors were fantastic because so many of the things they wrote about have come to pass.

I don't need the special powers of a 1960s superhero today. With what science has given me, I can see through the planet with X-ray vision! Lift enormous weights with a super-strong exoskeleton! Run through a battlefield, with bullets bouncing off me! So science makes superheroes look ordinary – or as I prefer to see it, ordinary people with science are superheroes.

I look at the possibilities of the world today. I cast my mind forward to the even more extraordinary possibilities of the world ahead. And I'm filled with excitement about the lives my grandchildren and their children might one day enjoy.

On the other hand, I'm terrified at the thought of a world divided between superheroes with science, and strugglers without it. And the difference I see between those two groups comes down, in large part, to education.

Of course, it's not just a question of education. It's about access to resources, attitudes in society and opportunities in the workplace as well. But with education we have a shot of overcoming disadvantage – the best shot in life we're likely to get. And I see all too many indications that we are headed down the path to deeper division, a division that diminishes us all.

A national scorecard for secondary science and maths

The scorecard I am releasing today doesn't contain new data. It simply sets out the hard reality this audience confronts every day, focusing on science and mathematics in Australian secondary schools. It is the baseline, from which we hope to see improvement.

In 2003, in the PISA tests run by the OECD, we ranked fifth in the world in maths, with a score of 524. In 2012, we ranked 17th, with a score of 504. So we declined, judged against ourselves, and judged against the rest of the world.

The same is true in science, if not as stark. In 2006, we ranked fourth in the world, with a PISA score of 527. In 2012, we ranked eighth, with a score of 521. We could say that's great, where's the problem in a fall of six points? I say it's a problem that our students are, at best, only just declining. I say it's a problem that any decline could ever be accepted as a decent result.

But probe into that decline, and the situation becomes even more concerning. There is, on average, a two-year achievement gap between our best and worst-performing states in mathematics. There is a year-and-a-half gap between our best and worst-performing states in science. Do we think that children in the ACT are somehow born two years smarter? As much as I respect Canberrans, I don't believe that's true.

Then delve deeper to look at the divide between cities and regions. Again, in mathematics, we see on average, a two-year advantage for students in urban areas compared to students with regional postcodes. And again, in science, it's a year and a half.

But worst of all is the divide between students on what we call socioeconomic grounds. In science and mathematics, the gap between students from high SES homes and low SES homes is the equivalent of two-and-a-half years of education. Thirty months or 10 terms in school.

That puts some context behind the curious report I encountered the other day. In the TIMSS study, students who reported having more than 200 books in the home scored, on average, 101 points higher in science than those with fewer than 25 books in their homes. That's an achievement gap of close to three years. It's a correlation, not causation. But it says a lot.

Friends, we have the good fortune to live in one of the most prosperous societies on the face of the planet. Today, the average person born in Australia lives longer, and better, than the aristocrats of our grandparents' time. And yet we are sliding down the global ranks as a country. And we are blowing out the opportunity gap at home. What on Earth are we doing and how is this allowed to go on?

So I'm fired with the passion to get Australian science and mathematics education right. And I don't mean by dragging down the children who are already thriving. I mean by lifting up every child as a superhero, with incredible opportunities that are just dancing at the edges of my imagination today. In fact, I want the schoolchildren of 2050 to look back at the way I live now and laugh because it's all so boring and backwards. And I have to point out I drive a Tesla electric car!

It's pretty clear to me that achieving that dream comes down to two groups of people – teachers and parents. It is enormously difficult for me to speak to parents directly. So for me, the most important people to reach are teachers.

I know I don't need to tell you about the importance of the subjects you teach, but I offer what I can to support you to teach them well. And I want to encourage you to be critical advocates for science, reaching out to the people we really need to persuade, the millions of Australian mums and dads.

The path to the target

Now when I see a big problem to solve, I tend to react like Clark Kent. Jump into the telephone box, strap on the cape and fly. In my case, I head to the airport and get on an aeroplane.

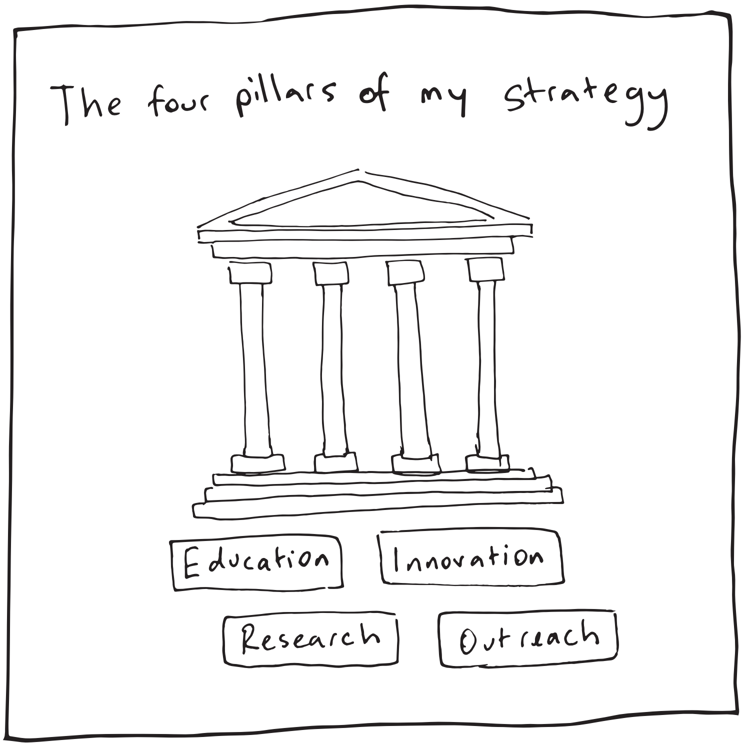
In my first three months as Chief Scientist, I attended 174 meetings, delivered 24 keynote speeches and stumped up to 15 media interviews. It was important to me to introduce myself, hear from people, and make my wholehearted commitment to this mission abundantly clear.

Since that time, you could say I have gone back to the Crystal Palace – more formally known as the Fortress of Solitude – to develop the detailed plans. For the last four weeks, I have been working on a three-year strategy for the Office of the Chief Scientist. I'm glad to say that strategy is ready to hit the Science and Education Ministers' inboxes very soon. And I hope you won't mind acting as my focus group today.

I have built my vision on four pillars: education, research, innovation and outreach.

Education, let me reiterate, comes first. In my mind I tend to divide it in three: a quality education is the sum total of the curriculum, the extra-curricular opportunities and the teaching.

I look at the curriculum and I don't see any opportunities for me to intervene in a helpful way. I look at the extracurricular opportunities and I see enormous potential, as I'll discuss. And I look at teaching and I see how vital it is for me to do whatever I can to empower you, the experts.



This is the Roy Stanhope Oration, so I will say it again: teaching is a profession. It demands a professional's skills. It is a title that some of the great men and women of history have been proud to hold. You are national assets, and for me, critical allies.

So I wanted to use the remainder of my time today to outline not just some of my ideas, but my ethos and approach. I've had a couple of decades in research, innovation strategy and science education to reflect on these themes. In that time, I have:

- created the STELR program, through the Academy of Technology and Engineering;
- started the Cosmos for Schools program, through the nation's finest science publication, now in the hands of the nation's finest editor, who is coincidentally my wife; and
- built an early-career researcher training program for brain scientists.

And now I've squeezed all of that thinking and doing into four key messages. Let's fly!

Message number one, aim high, with aspiration. Wherever I look at the education system, I see incentives to lower our expectations. There are aspiration-lowering incentives for students.

Why study maths at the advanced level, if your ATAR will be higher if you stick with intermediate? Why study maths or a science at all, if you can get into your chosen university course without it, because there are no pre-requisites to get in the way? Students ask these questions of career counsellors every day. As the system operates today, it makes sense for them to do so.

> ***"Students, principals and teachers are making rational decisions that perpetuate an entirely irrational system-wide decline"***

But when students and parents opt out, that gives school principals the incentive to opt out, too. Why pay for great programs that students don't want? And I can see that it must be very tempting for a teacher to try to hang on to students by making the lessons as easy as possible.

So we have three groups of people – students, principals and teachers – making rational decisions that perpetuate an entirely irrational system-wide decline. There is nothing crueller to children than a culture of low expectations. It blinds our children to their own potential, and it blinds this country to the outcomes we could achieve if we moved the dial from lowest common denominator.

So one of my key initiatives over the next three years will be to shift the dial. We need to build in reasons for schools to reach for excellence, and recognition for those schools that achieve results.

In my mind and in my strategy plan, I am beginning to envisage an aspirational awards program for schools, to encourage and reward their progress in maths and science education. My interest is in progress, not school rankings or league tables. I don't want to reward schools for excelling today, although I certainly want to learn from those schools about how it's done. I want to see recognition for all schools that commit to getting better, regardless of the position from which they start.

> ***“There is nothing crueller to children than a culture of low expectation - it blinds our children to their own potential, and it blinds this country to the outcomes we could achieve if we moved the dial from lowest common denominator”***

So, message number one, aspire to great heights and work to empower those who do.

Which brings me to message number two: think smart, with realism.

There are many people in the world today who think they have the answer to all the problems in education. We could have humanoid robots teaching the lessons! We could require students to wear brain-boosting electric stimulators on their heads! At the other extreme, we could start every lesson with 15 minutes of colouring in and singing! I think we can respectfully but firmly park those ideas to the side.

Then there are other people who do have insight and expertise, and genuinely well-informed ideas for education. We need those people.

But how often do we decide to pursue something new, without looking about to see what's already being done? How often do we miss the opportunity to scale up a pilot program with a model actually proven to work? How often do we rush an idea from drawing board to delivery without testing it first? I suspect the answer is all too often, and the outcome is the plethora of extracurricular and cocurricular programs we see today.

Of course, it is a good thing when teachers have a broad range of tools – by which I mean high-quality, stress-tested tools. It is also a good thing when teachers can adapt good programs to the local context. It is not a good thing to sprinkle resources across programs that schools can't access, implement or sustain when the funding ends.

As Chief Scientist, I have a tremendous advantage. I can look across the system, and think like an engineer. I don't need to reinvent the wheel, or rebuild a segment of the wheel that already functions pretty well. I just need to work out how I can help to optimise the wheel's performance. In particular, I can help to make connections.

This year we released the book that Vic Dobos has helped me to distribute here, the STEM Program Index, or SPI Guide. It is a catalogue of education programs offered by companies, universities, philanthropic groups and others, to complement the core work that teachers do in schools. It's good. But it's limited. From the moment we hit print, it was out of date. From the moment we sent it out, we started hearing it was incomplete.

So we don't want a second-edition book. We want the equivalent of a TripAdvisor portal. A powerful online repository that is easy to access and easy to search in fine-grained detail, and where it is easy to post reviews. We're working on it as part of the strategy, and I'll have more to say in the next few months.

And so to message number three: lead from the top, with conviction.

I've tried to achieve many hard things over the years, some with more success than others. I've learned that it's not enough to have a good idea and a personal commitment. It simply doesn't work unless you can persuade others to come along.

This is particularly true when it comes to the education of our children. There is nothing more precious to parents than their children. There is no greater anxiety than the fear that we're missing the chance to get their future right. As a parent, I know that anxiety and sense of obligation. I also know that teachers commit to this profession because they care very deeply. They certainly don't do it for the pay. So I don't have to persuade the important people to care. I do have to persuade people that the goal is achievable, and the path is sound. I also have to show that I'm prepared to gather the evidence, learn from the experts and be held to account.

This evening I have declared to you my strategic intent for two new programs. And the judges of those programs will be the people in this room. So CONASTA 2018, book me in! And until we get there, I'm looking to you to keep me up to the mark.

And finally message number four: don't forget message number one, aspiration.

I know that progress in this mission can seem at times to be painfully slow. The impacts may not be felt for many years, and all the inconvenience and grief is carried today. But that's science – reaching today for something hiding in the future. We're in the wrong room if we plan to waste our time on something easy. As Roy Stanhope's torchbearers, we must not give up because the going gets hard.

It's right there in the conference brochure – you're superheroes. A genuine league of superheroes. And it's written into the script that the superhero always wins. And so can we.

I promise my utmost resolve for the next three years. I welcome your companionship and advice. And let me leave you with a challenge for the year ahead, because superheroes without a challenge are just people running round in capes. Help me to act on the strategic intentions I've declared today. Help me to get these programs right. And help me to explain them in ways that principals and parents can understand.

Remember, the vision is a nation that leaps tall buildings. The starting point is a nation in the elevator, heading down. And up there in the sky, it's not a bird, it's not a plane. It's a science teacher. Let's get out there and save the day.

9. Renewing the Signals, Restoring the Continuum

July 12 2019 | Opening Keynote Address at the Australian Association of Mathematics Teachers 2019 National Conference

I have a brass plaque on my office door quoting Plato: "Let no-one ignorant of geometry enter here." From Plato to the great universities of medieval Europe where every student studied arithmetic and geometry, mathematics has been at the core of the best education. This address to mathematics teachers characterises mathematics as a training ground for logical thinking, step-by-step solving of complex problems and focus. Add English and you gain a wealth of knowledge that has gone before and the ability to communicate ideas now. Add sport and music and you can also master the languages of the body and the emotions. This is an education. It's not an ATAR.

Since this is the closing session of a mathematics conference, I'm going to start with a mathematics problem. Pencils ready? Here it is, and I've been nice, it's multiple choice. In the time it takes an unfit runner to cover 60 paces, a fit runner can go 100 paces. The unfit runner has covered a distance of 100 paces before the fit runner sets off in pursuit. How many paces does it take the fit runner before she catches up to the unfit runner?

A) 150
B) 160
C) 250
D) 260

Now I'm going to make a confession: I didn't write that problem. It's from an ancient Chinese textbook that dates back to at least 200 BC, and possibly centuries before. It's called *The Nine Chapters on the Mathematical Art*, and it's a collection of 246 problems demonstrating the practical applications of mathematics to ancient Chinese life.

What could you do with mathematics in ancient China? Well, in ancient China there are problems on calculating distances. There are problems on trading commodities like millet and rice. There are problems on collecting the right amount of tax. There are problems on building canals, and ditches and dams. There are problems on predicting farm yields.

So, the answer to "why mathematics" in ancient China was "because without mathematics our civilisation will collapse". And the message to young scholars was clear. If you wanted to climb up the rungs of society by getting an education and joining the civil service, then this was content you absolutely needed to know.

Now this insight was not unique to ancient China. Mathematics has been part of the curriculum for at least 4000 years.

Let's journey back in time to the first known complex civilisation, ancient Sumer, where writing was first developed. In ancient Sumer there was an elite class of high-skill workers: the scribes. Scribe school would start with the Sumerian alphabet. Then they'd have to memorise the sign combinations for hundreds and hundreds of words. Next was simple arithmetic, metrology, algebra, geometry and some trigonometry. With that under their belts, they'd move on to accounting, and contract-writing, and law.

Why mathematics in ancient Sumer? Again, because without mathematics civilisation would collapse.

And civilisation ticked along all the way to ancient Greece, and a person you might have heard of, named Plato. At roughly the same time as *The Nine Chapters on the Mathematical Art* was coming together in China, Plato was also educating Athenians in the importance of mathematics. In his classic work *Republic*, he sets out very clearly what an ideal education would look like. Language and literature. Physical education. A bit of military training. And 10 years of mathematics.

Mathematics was so important to Plato that he made it a prerequisite for entering his academy. He had it engraved on a plaque by the door: Let no-one ignorant of geometry enter here.

Which I interpret to mean a requirement for at least intermediate mathematics, with a preference for advanced. Don't tell me Plato wouldn't have required calculus if it had been invented. Of course he would have insisted on calculus. Case closed.

> ***"Don't tell me Plato wouldn't have required calculus if it had been invented - of course he would have insisted on calculus"***

Skip forward 1500 years. The great universities of medieval Europe are born. And they look back at what worked in ancient times, and they come up with a three-part structure for the academic curriculum. First, the trivium: three years of grammar, rhetoric and logic. Second, the quadrivium: four years of arithmetic, geometry, astronomy and music. Third, an optional doctorate in theology, philosophy, medicine or law. The point is that you don't get to be a master or a doctor of *anything* unless you study mathematics.

So, there's nothing original about the message I'm here to give today, that mathematics is important, and it has to be a priority. The answer to the question "why mathematics" has been obvious for 5000 years. But again and again, we seem to forget.

So today I want to reiterate what I mean when I say that the priority has to be mathematics. I want to talk about the factors that discourage students from taking mathematics at the level of their real ability in their senior years. I want to talk about the consequences for students who miss out on the mathematics foundations that they ought to be building in school. And I want to talk about what we can do to make inroads on what we all acknowledge to be an entrenched cycle that sets up far too many students for disappointment.

Now, as you are a captive audience, and one with a vested interest in the topic, I am happy to give you my answer to your question, why mathematics? Well, in my view, it's not just about mathematics – but I will get to it.

Students need in their muscle memory four key things. Most important of all is mastery of, in the context of our community, the English language, the language of discourse – to empower them to discuss politics and philosophy, to read Shakespeare, Charlotte Bronte, Ursula le Guin and Tim Winton. It must resonate in their minds to support the development of core communication skills and give them the ability to express themselves with confidence and with reference to history and culture. To quote Dr Seuss, "Sometimes you will never know the value of something, until it becomes a memory."

And then they will, of course, also need mathematics, the language of science. It's a common comment from students, and their parents and carers: why do I have to learn algebra? Or, why do I have to be able to estimate weight and distance? But when they are learning to drive and need to estimate speeds on the road, or work out the angle of a car park, or estimate the weight of goods, or build a house – or more importantly, pay someone else to build their house – the value of these skills and knowledge will hit them, hard. Or at least a light bulb will go on. And well-developed basic mathematical skills become the key for students who do want to explore mathematics further, as a necessary skill for future studies in fields such as science and economics.

In addition to English and mathematics, we also need sport, the language of the body. The Greek philosopher Thales had it right – a sound mind is a sound body. And music, the language of emotion, a vehicle to express yourself without words. A divine skill. I often wish I had gone down that path.

What do English, mathematics, music and sport have in common? To be good at them you need muscle memory, which comes from learning and practising, learning and practising, year upon year upon year. Whatever path a student chooses, laying down the core skills of the discipline is vital.

So, if we all agree that mathematics is important, and I am sure that everyone here does, why are fewer students choosing to study it at intermediate and advanced levels?

Many of you may be aware of the work of my office is doing, along with the Australian Mathematical Sciences Institute and others, to better understand the reasons for the drop off in numbers of students choosing to study mathematics at every level, and in particular at senior secondary school.

We know the issues are complex, including a perception that with computers and smartphones, mathematics is no longer needed. We know that there are a wide range of factors that influence students' subject choices, and their performance. Parents and friends play a huge role, but teachers have the greatest in-school influence.

For mathematics in particular, there are a number of motivating, or demotivating, factors, including how it's being taught, the capacity of the teacher to teach the subject, and whether there are other more attractive options for students to increase their ATAR.

We know that the majority of students select their courses with an eye to a single number – the ATAR required to get into a particular course. And rightly or wrongly, they absorb the message that the way to boost their ATAR is to drop down a level of mathematics. Linked to this is the schoolyard chatter that goes on in years 9 and 10, although these days it also happens online. The messages get confused, and inevitably end up being misunderstood by the year 10 students who are trying to decide their best option for subject choices in senior high school.

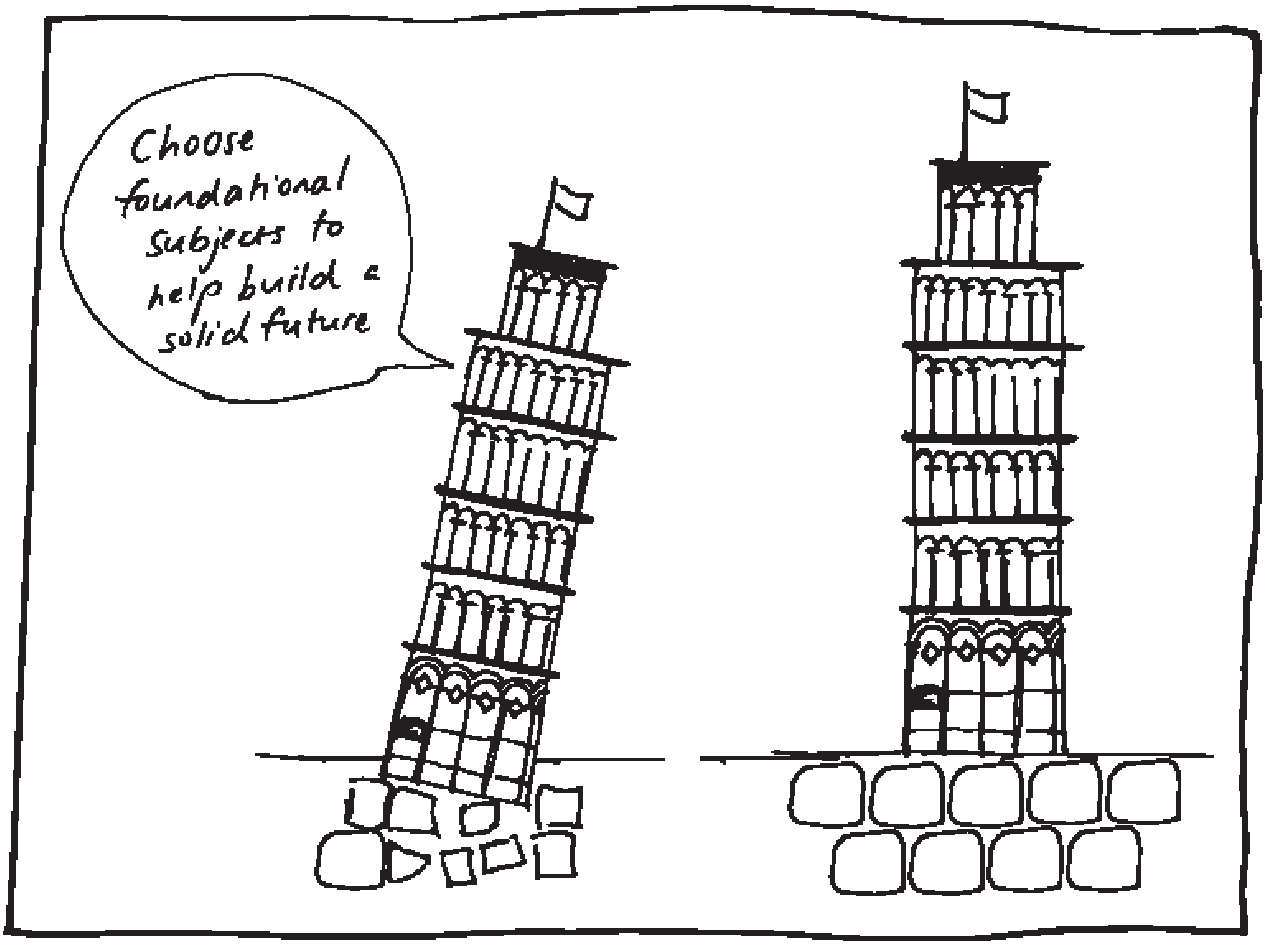
They are told, and the university course guides confirm through omission, that the higher their ATAR, the best chance they have of getting into their chosen course at university. But what happens if they attain the necessary ATAR for admission to a university course, but are not competent in the subject content to do well at university, often because they haven't stuck with mathematics?

In the past, universities made it clear the subjects that students should study to be prepared for the range of undergraduate courses into which they might want to enrol. Today, with some exceptions, Australian universities have removed or softened course entry requirements. This trend can be traced back to the 1990s, but it appears to have accelerated with the massification of higher education and the uncapping of places.

In the absence of prerequisites and clear signals of what is required to succeed in a course, the ATAR has been given more prominence than was intended. It is now used as a catch-all representation of student achievement, which it was never meant to be. The ATAR was originally designed to coexist alongside clear expectations and signals from universities about subject choice. Without these signals, the pressure to study subjects that are seen to maximise your ATAR score has increased.

So while an ATAR score may allow students entry to a course, without a sound understanding of core content students scrape through, or fail, or drop out. With all the consequences.

A few weeks ago the Productivity Commission released a report on *The Demand Driven University System*. It contains some fascinating information on the outcomes of the recent policy changes' impact on under-represented equity groups. It notes that there has been success in achieving an increase in the number of students attending university and improving equity of access. However, many students are ill-prepared when they enter university and they struggle academically. These students are less likely to complete their studies. While university attendance increased substantially under the demand-driven system, growth among equity groups has been uneven.



So with this trend of unpreparedness among a range of students, what changes can be made to try to address some of these issues? Firstly, like all drive for change, there needs to be leadership in addressing the problems.

Our universities need to indicate clearly to students what subjects are required to do well in a given course, and reinstate the expectation of studying mathematics at intermediate or advanced levels, particularly for entry into mathematics-based courses such as physics and engineering, and all of the general science courses, as well as other disciplines that depend on mathematics, such as economics, commerce and architecture. And medicine. Call me nervous, but I like to think that my treating physician is competent at mathematics.

Those expectations need to be communicated to all stakeholders – students, principals, careers advisors, teachers, parents, and those online influencers. Universities need to work together to develop an approach and communicate expectations clearly and consistently in language that is easily understood.

In the United Kingdom, the Russell Group is a grouping of 24 universities from around the country. It publishes a printed guide designed to explain to students 14 years and older the specific subjects that are needed in secondary school to gain entry to undergraduate courses in those universities.

It includes a list of eight core or "facilitating" subjects that, in addition to English, are more frequently required for entry to undergraduate courses than other subjects. These are mathematics, English literature, physics, biology, chemistry, geography, history and languages. Students are advised that including a selection of facilitating subjects at the advanced level will open up a wider range of degree choices.

In May 2019, the Russell Group's Informed Choices guide was relaunched as an online interactive guide. Students can see which subjects are recommended for specific degrees, and also test combinations of school subjects to see which degree paths they open up. According to the Russell Group, the renewed guidance "is particularly targeted towards supporting less advantaged pupils" who may not have access to high-quality advice elsewhere.

Of course, there are other sources of information, but the beauty of Informed Choices is that it is not about how to play the system. Instead, it is about how to optimise one's preparation for future studies without having to guess at the age of 15 what you might want to study at the age of 20, or work on at the age of 25.

It is my hope that a modest number of thought-leading universities will agree to develop an Australian Informed Choices. And I further hope most of those thought-leading universities will make it clear to students through prerequisites that they need to study mathematics in school in order to enrol in courses that need mathematics.

Mathematics is not a subject that you can pick up late in one's academic career.
The evidence that short bridging courses are effective is slim, the evidence that they are inadequate is much greater.

I would like to complete my remarks on this note. Learning mathematics offers the student core foundational skills for success. Until universities step up to the plate and send a clear signal to students that if they want to keep their options open they should study intermediate or advanced mathematics in school it is left to principals and teachers to encourage their students.

Mathematics at upper secondary school does not have to be compulsory – but it ought to be compelling. Compelling by offering lessons set in a real-world context. Compelling by telling contemporary success stories, such as Jim Simons, whom I met briefly last week. He's an American mathematics professor who contributed to the mathematics of string theory and quantum field theory, then in the 1980s decided to apply his mathematics skills to financial trading. He used mathematics to make money, and built his net worth to nearly $30 billion.

> ***"Mathematics at upper secondary school does not have to be compulsory – but it ought to be compelling"***

Jim Simons, like you, would have worked out in a heartbeat the answer to that ancient Chinese problem that I posed at the beginning of my speech. The answer is C: 250 paces.

Mathematics encourages logical thought. It allows for the laying out of a problem and working through solutions. It trains you to make deductions from the learned assumptions of those who have gone before. And it encourages you to apply your knowledge to a wider world view. It's a bit like being a Jedi master.

May the Force be with you.

10. The Prerequisite for Success

December 7 2018 | Keynote Presentation to the Mathematical Association of Victoria's annual conference

While my two sons were very young and captive in the back of the car as we drove between activities, we played constant counting games involving truck wheels and other roadside items. They learned, and didn't even realise they were learning. None of us know the answer to six times seven without first learning it – recounting it, practising it, ingraining it, setting up that mental pathway to 42. We don't learn calculus by osmosis, or watching a cup of tea cool down. Learning is doing the hard yards – and just like learning a musical instrument and playing a sport, the mental and physical pathways are best started young and require reinforcement through repetition. For students, this means ignoring suggestions on how to game the ATAR and focusing on learning the detailed, foundational skills in maths and other subjects. For schools, this means employing specialist teachers in mathematics and other areas of the curriculum. And for universities and in other post-school learning, this means much clearer signals to students about what they should study at school. At every level of the system, our expectations must be high, and high enough to do justice to the potential in our children. This speech was to mathematics educators.

The organisers promised you a fiery speech on the importance of mathematics. I promise not to disappoint the organisers. After all, they are providing morning tea for all of us.

But first, I want to take a moment to bask in the glory of this astonishing year of triumphs for Australian maths. 2018: a composite number composed of two prime numbers multiplied together. But more to the point, a vintage year.

We began in January, with the Australia Day Awards. Australia, meet the Head of Maths from Cherrybrook High, Mr Eddie Woo – teacher, YouTuber and now, officially, our Local Hero.

Then it was May, and Australian mathematician Geordie Williamson was elected at the age of just 36 as the youngest living fellow of the Royal Society. And not just the youngest living fellow in maths, the youngest living fellow, full stop, barring only Prince William – who I think we can agree, is in a category of his own.

To July, and what brilliant news from Romania! Two golds, three silvers and a bronze for our students at the International Mathematical Olympiad, for an overall ranking of 11th – our best performance since 2015, and our third best of all time. And 40% of the Mathematics Olympiad teams were from Victoria.

Also in July, and right here in Melbourne, an Australian team of students took out first place in the International Mathematical Modelling Challenge for the first time. And Nalini Joshi, the first female professor of mathematics at the University of Sydney, was elected Vice-President of the International Mathematical Union, the highest position in the global maths community that an Australian has ever held.

Fields Medal
CREDIT: Wikimedia Commons, CC BY

To August, and now it's the Fields Medal. "What's the Fields Medal?" said every news reporter in the country. Only the Nobel Prize for Mathematics, of course, with the difference being that you've got to wait four years for each announcement, and only 60 people in history have ever received it. And we can now add a second Australian name to that honour roll: Professor Akshay Venkatesh, also just 36.

Then, and still in October, we're gathered again in Parliament House for the Prime Minister's Prizes for Science.

And Prime Minister Scott Morrison, in one of his very first speeches as PM, went to the podium and said these words, and I'm going to quote them, because I keep them on file: *"Do you think intermediate level maths should be a prerequisite for studying engineering at uni? You'd think so. I would think so."*

"And as Vice-Chancellors come to see me, asking me their usual questions … I'm going to ask them: what are your prerequisites for science and engineering courses when it comes to maths?"

"We do need to reassert the importance of science and maths because that is essential if we're to have the pipeline of students that we require."

Also in October we heard the news that Alison Harcourt had been named 2019 Victorian Senior Australian of the Year, recognising her life-long, and continuing, contribution to mathematics and statistics. At the age of 89, Alison continues to share her knowledge and passion as a tutor at the University of Melbourne.

And finally, to November, and who's in the news again but Professor Geordie Williamson. He's getting on a bit now – he's 37, but he's clearly still in a hurry, because he's returning to Australia to head up our first specialist research institute for maths.

And then to December, and the news was seismic in scale, but bittersweet. Geoff Prince, the voice and heart and backbone of Australian maths, is stepping down after 14 years at the helm of the Australian Mathematical Sciences Institute. Geoff, I can only say it's been an honour.

It's only 7 December. We've still got time for a few more wins. And I know that there are many thousands of triumphs that I haven't covered.

I mean the sort of triumphs that happen in the classroom every day – when a student, who couldn't turn a decimal into a fraction, and was starting to think she hated maths, and was this close to ripping up the page and giving up, felt something click. And so many things about the world just made sense, from the price stickers in the supermarket to the numbers on the kitchen scales. Every time it happens, it's a win for maths. And every win for maths is a win for the nation.

So I acknowledge all those students, and I celebrate all their triumphs, with the teachers who brought them every step of the way.

* * *

But December is not just a time for celebrating achievement. It's the time for reflecting on what comes next. Teachers are knuckling down to the piles of school reports. Parents are looking forward to receiving them. And students might be turning their minds to their subject choices for the years ahead.

Now, it's been a long time since I was one of those parents, and even longer since I was a student. But you don't forget what it's like to be young – and to feel like you're taking your future in your hands.

And every so often a parent or a student will write to me, seeking my advice. I got one of those emails this year. And I am sincerely grateful to the family, particularly the student, Marty, for the conversation that followed.

It's one thing to be invited to conferences, which is a routine part of my role as Chief Scientist. It's a different thing altogether to be invited into a family circle. You can't squib. You can't agree to initiate a process to develop an outline for a blueprint for a discussion paper for a report. You have to focus on what's important and commit. And it occurred to me that that's exactly what teachers have to do every day.

So I gathered up my thoughts, and I communicated them to Marty and his dad. And I want to share my thoughts with you today, as my philosophy for what really counts.

* * *

I began with the essentials. If I could only pick two subjects that every Australian would study for as long as possible in school, it would be English and mathematics.

And there are three reasons why I say this and I trust that every parent will agree. One, they're fundamental. English is fundamental, because it's the way that we convey the thoughts and feelings from one human to another. It's how we reason, and argue, and imagine, and connect. On the practical level, it's how we write the cover letters that get us jobs. You need it.

And maths is also fundamental, because it's the universal language of the modern world. Maths is the language of science. And economics. And medicine. And engineering. It's how we describe the increase of the money supply in our economy and the flow of heat in an electric motor. It's how we work out the lifetime cost of a real-estate deal and the thickness of steel to ensure that new buildings will not collapse.

> ***"It might be that a child wakes up on day one, and doesn't feel like doing her mental arithmetic, but we don't let children starve because they say they don't feel like eating; we don't let them go unwashed for a month because they decide they don't like baths"***

So reason one, English and maths are fundamental. Reason two, they have to be learned, and that means they have to be taught, by subject matter specialists, in schools. It's true that the human brain is an astonishing thing. And humans, left to their own devices, without education, will grapple desperately for ways to communicate, and to count.

But we don't learn calculus by watching a cup of tea cool down. And we can't have any comprehension of what calculus is – let alone how we might want to use it – if we don't start laying down the maths foundations from day one.

Now it might be that a child wakes up on day one, and doesn't feel like doing her mental arithmetic. But we don't let children starve because they say they don't feel like eating. We don't let them go unwashed for a month because they decide they don't like baths. And to my mind, it is just as cruel to give them the choice about maths, at an age when they cannot possibly fathom the consequences. We have to make the choice today, so that they will have choices tomorrow.

That goes for boys, and for girls – they are equally deserving of our high expectations and our constant support. And that brings me to reason three for English and maths: they're empowering. They enable us to learn new things later on.

Here is a list of things I didn't study in school:

- computer coding
- neuroscience
- electrophysiology
- electronic circuit design
- flying a plane
- writing librettos for a symphony orchestra
- scuba diving
- property development

But all of those things were open to me as an adult, and I know, because I've done them. And all because I had the essential foundations, from school, in English and maths. Trust me, you don't want to fly with a pilot who can't count.

So start with the two basics, English and mathematics, and from there build up your knowledge of the world around us by studying subjects like history or chemistry.

There are two other studies that I encourage everyone to keep up for as long as possible from an early age: a musical instrument and a sport. Music is sometimes called the language of the soul, the emotions. And sport is the language of the body. Just like English and maths, they are our shared inheritance, with their own rules and conventions and codes. And just like English and maths, if you don't practise music and sport as a child, then you have to work incredibly hard to get half as far as an adult.

* * *

So you can see, I said to Marty, that I'm approaching this question as a matter of stocking your mind.

Now let's talk about your ATAR. Do not under any circumstances choose your subjects by deciding the ATAR you want and working backwards to the easiest way of obtaining it. You will be told by people who pretend to be wise in the mysterious ways of ATAR that the higher the number, the wider your choice.

They are wrong. Ignore them. Stay strong. Because those people are only thinking about the number that might get you into a university. They're not thinking about the skills you actually need to come out of that university with a degree.

You need to know, I said to Marty, that there are universities in this country that will accept you into an engineering course, or a science course, or an economics course, despite them knowing that you don't have the foundation skills in maths.

You also need to know what happens to students who take that guidance in good faith, drop maths in Year 10, and turn up to university unprepared. They drop out. They fail. Or they scrape through at the bottom of the class. And then they're in no position to go out and compete for a job.

You think that's outrageous. I agree. The Prime Minister agrees. Almost everyone agrees! And nothing changes. No, I can't explain it either. But now that you know, you can avoid the trap.

Read into the course guides the prerequisites that universities have mysteriously left out. Study to equip your mind. In particular, take maths at the level of your true ability. And rest assured that your focus and discipline will make your time at university far more rewarding.

* * *

Another thing you'll hear, I said, is that specialising in anything is a waste of time. All you need are skills like teamwork and public speaking and resilience – not chemistry, engineering or law.

But let me tell you, I've built a business. I've hired hundreds of people. I know hundreds of people who've done the same thing. And that's how I know that the wrong way to build a business is with a group of capable people who collectively specialise in nothing at all. If you want to be the best in business, then you need real experts who can lift you above the generic thinking of everyone else.

You'll see them described in the business literature as "T-shaped workers". The pillar of the T is the discipline. It's the knowledge and skills that come as easily as breathing, the mastery you can only acquire through hard work and determination. Climb that pillar, and you can develop the bar, the capacity to work with others and branch out in new directions. When you're standing on that bar you look at life with a whole new perspective.
You see opportunities that no-one else can, and you trust yourself to take them.
So master a discipline, and give yourself the chance.

* * *

And there our conversation ended. But I couldn't get the topic off my mind. I felt the urge to call every high school student in the country, shouting "don't drop maths!" Of course, I'm a public servant these days, and I'm fairly confident that acting on that urge would be illegal.

In any event, much better than a phone call from the Chief Scientist would be crystal-clear guidance from the education system. So that students would always be nurtured in an environment of high expectation, with constant encouragement, and the message reinforced at every stage: this is important and you are capable.

I looked for those signals. And I felt like the scientists working to rescue threatened species. The signals are disappearing from university course guides. The signals are not there in the popular culture or the media. And the signals are certainly not there in the approach we take to those critical national assets: the people who specialise in the teaching of maths.

Why would you think that maths is important, if for every year of your secondary schooling you were taught by an out-of-field teacher? In a country like Australia, it seems impossible that that could be true. But we have the figures from the Australian Mathematical Sciences Institute. That's exactly what happens to eight percent of students. Less than one in four students is supported by qualified, expert maths teaching professionals, all the way from Year 7 to Year 10. And that's assuming a definition of "in-field teaching" that the institute considers inadequate: one semester of study at university.

The dedication of out-of-field teachers to their students is not the issue. The issue is the lack of commitment right across the system to the teaching of maths. And even if we woke up tomorrow and made it our top priority, the institute estimates it would take at least a decade to turn things around.

"It's the chicken and egg dilemma. Without great teachers, we don't develop confident students. Without confident students, we can't train enough great teachers."

It's the chicken and egg dilemma. Without great teachers, we don't develop confident students. Without confident students, we can't train enough great teachers.

I put my concerns to some deans of engineering and one of them said to me, "But Alan, if we were to reinstate mathematics prerequisites the schools would have a problem because there are not enough secondary-school mathematics teachers."

"Of course there aren't," I replied. "That's because universities have stopped signalling the importance of mathematics!"

We are in a spiral. So the question for me, and for this conference, is where and how to intervene.

***

Let me leave you with three of my recommendations, with a focus on what we can do right now, today.

Number one, keep up the pressure on universities to be a connected part of the education system. The lack of guidance provided to students about their subject choices is unacceptable. And until we see improvement, we will continue to send the wrong message to students, to parents and to principals.

Such as advising them to try to game the ATAR. And then we blame the ATAR. Wrong target. ATAR is not meant to stand alone. ATAR is intended to be a team player. ATAR plays best as the goalie among the team of prerequisites.

We shouldn't have to tell universities to face up to their responsibilities as part of the education continuum. For that matter, we shouldn't have to tell them that it's unacceptable to enrol students with a level of preparation that sets them up to fail. But as regrettable as it is, that's the position we're in.

If this worries you, take heart in that you are in a position to express your concerns to vice-chancellors. To let them know just how hard it is in the absence of a signal from the universities to persuade your students that yes, they really do need to take maths at a challenging level, all the way to the end of Year 12, if they want to keep the doors of opportunity open. Let's make it impossible for vice-chancellors to be ignorant of the fact that their policies have human implications and costs.

It *is* possible for universities to change their position on prerequisites. In 2016, the University of Sydney announced that it would be reintroducing mathematics prerequisites for 62 degrees, starting next year. I commend the University of Sydney for doing so and I am sure that every other Australian university will be watching closely.

Number two, we can do a much better job of celebrating those principals and schools and students who double-down on maths, and get the results. Australians have been told for a very long time that maths is in decline. And chief scientists and heads of mathematics institutes have been some of the people saying it. But too often the conversation stops short at "we have a national problem", before we get to the second half of the sentence: We can and will do better.

Maths teachers know better than anyone that when you set out to do something hard in the belief that you're hopeless and you're going to fail, it's amazing how often your prediction comes true. That's why great teachers create an atmosphere of high expectation, and pause to acknowledge success. We can all learn from the wisdom of teachers. And we don't have to imagine what success would look like. We can find the examples and pick out the common factors in actual schools.

Earlier this year, my office published an occasional paper drawing on some research we commissioned from the University of Tasmania. We didn't look for the top performing schools – instead we looked for the top improving schools, which we defined as those whose NAPLAN numeracy scores had significantly improved over a two-year period. We identified more than 600 schools.

What did those schools we surveyed have in common? Here were the top three characteristics:

1. Principals and heads of curriculum who understood and valued mathematics, and made a point of regularly including the heads of maths in policy discussions.
2. In-school support for professional learning – structured, embedded, and obligatory.
3. A cohort of maths teachers with confidence not just in the subject, but in their school, and its commitment to their development.

And none of those things should come as a surprise.

But I want the message to school leaders to be absolutely clear: the responsibility for progress doesn't just lie on the teachers. It doesn't just rest with the education departments and politicians. True, we need the universities to step up to the plate, but we cannot wait for them. Schools themselves need to address the problem. There is no better time than now. It comes down to the priorities and the policies of your school. And those are things within your power to improve. That's not to say that you shouldn't ask more from the system.

Which brings me to number three, elevating our commitment to teaching as a profession. When I think about what it means to be part of a profession, I think about the way that we train engineers. That was my chosen degree.

Engineering courses are accredited. They have to meet international standards. And if you want to land a senior position, then you'll want to show your employer that your name appears on the National Engineering Register. In Queensland, it's compulsory to be registered. In other parts of the country, it's strongly advised.

Then you have to maintain your registration, and that means meeting the requirement for continuing professional development. Currently, that's an average of 50 hours per year, with at least half focused on training that is specific to your discipline, such as civil engineering, or electrical or chemical engineering. And your employers know this when they hire you. They factor it in to the cost of employing accredited, professional engineers. Professional development is part of the package deal. So that's how I think of a profession: people we inherently trust, who can trust in turn that their employers will prioritise their discipline-specific training.

Why don't education departments include a requirement for discipline-specific training for teaching? I know that across the country teachers and organisations like the Mathematical Association of Victoria are already working hard to improve the professional status of teaching as a career.

As Chief Scientist, and as an individual who cares passionately about education, I ask: what more could the system be doing to support our teachers?

In the consultations undertaken for my report to the Commonwealth and state Education Ministers earlier this year on optimising the partnerships between businesses and schools in STEM education, the issue of the composition of the 20 hours of professional learning that teachers are already committed to undertaking every year came up frequently.

> ***"As Chief Scientist, and as an individual who cares passionately about education, I ask: what more could the system be doing to support our teachers?"***

As a result, in our report to the Ministers, we called for the strengthening of teacher professional learning to make sure that the 20 hours required per year includes a proportion of discipline-specific material. We also called for the discipline-specific training to be delivered by accredited providers. To be fair, principals and education departments have to make sure teachers have the time and resources to undertake it. And to be meaningful, it has to be part of the continuing registration process – just like it is for lawyers, just like it is for doctors, and just like it is for registered engineers.

So there are three ideas I'd like you to think about: encouraging the universities to send proper signals to students and schools, taking responsibility in our schools to implement best practices, and supporting all our teachers as the professionals they are.

And if 2018 was a great year for maths, then 2019 can be even better again.

May the Force be with you.

11. The Winning 2030 CV

November 21 2018 | Keynote Address to the 5th International STEM in Education Conference

A visit to the glow worm caves in Te Anau, New Zealand, with Elizabeth, Victor and Alex in the summer of 2017 helped me make the case for science and mathematics subjects in education. The township is small, wet and remote, the kick off point for visiting the scenic fiords, forested cliffs and raging waterfalls of Milford Sound. It is also home to the glow worm caves, where the appeal is about more than their beauty. For an engineer like me, the glow worms represent engineering genius as they convert chemical energy into luminescent energy. For an astronomer, they might seem more like a cosmological tableau. A biologist like my wife will be fascinated by the display of bioluminescence from these tiny life forms that use light to confound their prey and silk threads to entrap it. An entrepreneur might be inspired by the capacity of the New Zealanders to monetise a natural adventure. The lesson I took from the glow worms is that if you have deep knowledge of your subject, in whatever discipline, you are positioned for leaps in insight and understanding. Like an orchestra, those ideas across different specialities can coalesce to produce something bigger than the sum of its parts.

Today I want to set out my case for the enduring relevance of the disciplines. I want to advocate for a content-rich curriculum. And I want to focus in particular on the importance of teaching maths, in sequence, through a structured program, and at the level of a student's real ability.

But I want to get there by way of a parable. And I call my parable, The Light in the Cave. Subtitle: What I Did on My Holidays.

A few years ago, I travelled with my family to New Zealand. We decided to spend a few hours at the Te Anau caves, near the southwestern tip of the South Island. Every year, people flock there in their tens of thousands not so much for the caves – although they're stunning – but for the glow-worms.

Like a scene from *The Phantom of the Opera*, you step into a barge that glides silently through the water, shrouded by the subterranean darkness. Then you look up, and you're in a grotto, and all you can see are thousands upon thousands of tiny blue pin-points of light.

Now I'm an engineer, and the author of the Finkel Review of the National Electricity Market. It's hard to take off your hats when you're on holiday. So when I looked at those lights, I thought to myself, what a brilliant mechanism for the efficient conversion of chemical energy into light energy! It works like this. Glow-worms live on mosquitoes and midges. To catch them, they dangle an invisible web of silken threads and switch on their lights. The light confounds the prey, then the silk entangles the victims. And the victims provide the energy to keep the lights on. Genius. So that's what I saw in the cave, engineering inspiration.

Then there's my wife, a life scientist. She can tell you that glow-worms are found only in Australia and New Zealand. And she's also the very recently retired editor of *Cosmos* magazine. So she knows a lot about the natural phenomenon of bioluminescence.

Today, we can isolate the luminescent and fluorescent proteins in creatures like glow-worms and jellyfish. And we use gene-editing techniques to modify, for example, the neurons in a fruit fly, so that they flash in different colours depending on the level of electrical activity. That means we can take images of complex structures like the brain in glorious technicolour. We move ever closer to answers to the cruellest conditions – dementia, motor neurone disease, schizophrenia. So that's my wife's perspective – great science, great pictures and great material for *Cosmos*.

Then there's my older son, Victor. He's a management consultant. He deeply respects the Kiwi capacity to monetise what is, when you think about it, colonies of fungus gnats living on mosquitoes in a cave.

And my younger son, Alex. He's a software engineer who appreciates the way the tour operator keeps iterating and improving the experience.

And as I stepped off the barge I wondered. Would an astronomer look up, and see a living galaxy of stars? Would an airline pilot be reminded of the view from the cockpit, flying over a city at night? Would a historian be intrigued by all the myths and legends we've used to explain this phenomenon over the centuries? I wish I'd had more time to ask.

But just from my sample group of four, it was clear. Every one of us, with a grounding in a discipline, stepped off that boat with something distinctive to say. We'd seen the world in different patterns. And we'd imagined its possibilities in many forms.

That's the Parable of the Light in the Cave.

* * *

When I was a student the importance of actually specialising in something – mastering a discipline – was more or less assumed. We thought about the skills mix of our future society in the same way we imagined an orchestra.

You want a broad mix of people who excel in a range of speciality fields. Yes, we do want those people to be able to play together. And we want them to sound like an orchestra, not several dozen simultaneous solos. That means, if you'll excuse the pun, that every one of those musicians needs to have at least two strings to their bow – a primary discipline, the instrument; and a secondary discipline, orchestral performance.

> ***"Discipline is like a ladder – you have to put in the effort to climb it, step by step, with structure and sequence, accepting the guidance of your teachers"***

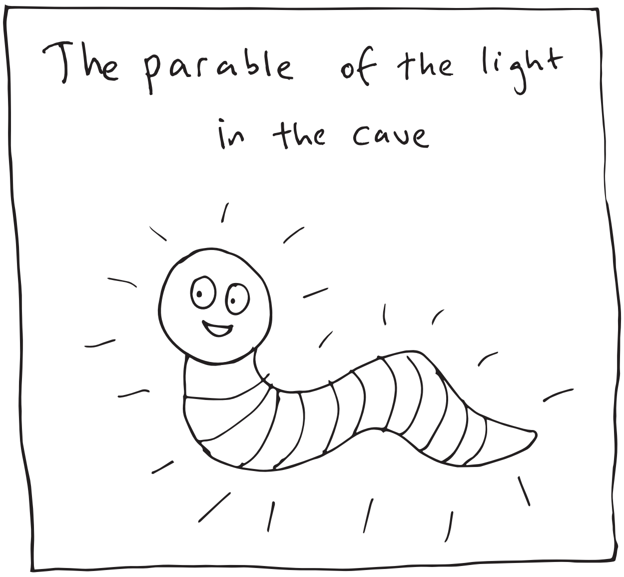
But they can't master the secondary discipline without reaching a level of proficiency in their instruments first. And if you think you can, I challenge you to give a clarinet to a 10-year-old and enrol her on the same day into the school band. Now, that student could have a genuine passion and talent for music, but until she can manage her fingers, and the breathing, and read music, and produce a noise that isn't a brain-splitting shriek, she's got to knuckle down and practise. Solo.

Focus on your discipline, *then* you'll see your options expand.

And I internalised that logic. I now understand that a discipline is like a ladder. You have to put in the effort to climb it, step by step, with structure and sequence, accepting the guidance of your teachers. Learn the principle. Do the practice. Apply the skills. Repeat.

In particular, that's the approach my parents and teachers took to my mathematical education. They didn't leave it to me to decide. Of course, they didn't know what I might one day want to do at university. *I* didn't know what I wanted to do at university.

But right from the beginning, they knew that maths was likely to be extremely important, and mastering it would maximise my choices. So they made sure that I worked at it until I didn't have to work at it, starting with the times tables. At first, I had to stop and think all the time. It was tedious. But I wanted to do well. That made me determined. And soon enough I could see "11 times 12" or "nine squared" and the answer just sprang up in my mind unbidden, so that I wasn't even conscious my brain was doing any work.



By the time I got to university I had reached a level of proficiency that allowed me to devote all my mental energy to mastering engineering. Again, I worked at it. I became an incurable engineer just like I'd become a human calculator – rung by rung, climbing the ladder.

The next step for me was setting up a company, Axon Instruments, to commercialise a technology I'd developed in the course of my PhD and post-doc.

One of the first things I had to do was staff it. In the early days, that was very easy. It was a one-person company, and that person was me. I got on very well with myself. But at the time I only had one product. And everything about it could be handled within my skillset. Then people started buying my product. And other people started dreaming up ways to better it. And if I wanted to stay in business, then my company had to develop more sophisticated technologies, and expand. And so, for the first time, I had to extrapolate from my own experience to the broader question of what makes a good professional CV, for people with skillsets very different from my own.

When you're in business, it's not an abstract inquiry. I had to stake my own money, and my company's reputation, and my family's future, on my ability to determine which candidates were best equipped to help me succeed.

And I was uncertain of many things at this point in my life – like my bank balance, because there were many, many days when I was too terrified to look at it.

But at least when it came to hiring, I knew exactly what I wanted. Discipline experts who could work together, not generalists who thought the same. I'm talking here about serious specialisation. For example, a first sub-specialty of electronics engineers expert in working with analogue circuits, and a second sub-speciality of electronics engineers expert in working with digital circuits. And the many experts I hired served Axon Instruments extraordinarily well.

> ***"On the contrary, the most creative candidates were usually the most capable, like virtuoso jazz players"***

In the end, I was employing nearly 150 people. That gave me the sample set to test and refine the selection methods, because that's how engineers are trained to think. It's all about optimising. We put job candidates through their paces with some seriously challenging scenarios. We called the interviews auditions.

It was always interesting to compare the candidates' academic transcripts to their performance in those auditions. For me, it confirmed once and for all that there's no tension between drilling extremely hard in your chosen subject and being extremely creative. On the contrary, the most creative candidates were usually the most capable, like virtuoso jazz players.

* * *

Since that time, I've seen a lot of teams, in business and in research, and I've sat on a lot of boards. I would still build my company exactly the same way. But I now have the life experience to confirm the wisdom of what I was taught: yes, you will go badly astray if you pick 10 people who collectively specialise in nothing at all.

And I worry that we, as a nation, will go the same way, if we take away from the next generation of workers the disciplinary ladders that we climbed ourselves. If we strip back the expectation that students will study hard content, in sequence, through direct instruction. And if we bulk out every study program with the same generic soft skill components. In short, if we raise a generation who come out of the glow-worm cave perhaps ready to talk, but with nothing distinctive to say.

Why would we take that route? There are any number of rationales presented, and usually, by thoughtful people, with the very best of intentions. The argument usually begins with the undeniable premise that we live in interesting times. The labour market is changing. And the robots are coming for our jobs.

How many robots, and which jobs? You can take your pick from the projections. The most famous study, from Oxford University, estimated that 47% of jobs in the United States were at risk of automation by 2030. That was published in 2013. Then four years later the numbers were revised. Now it was 27% – which only works out to a difference of approximately 43 million people. That's Oxford. The OECD says 14%. PriceWaterhouseCoopers says 37%. CitiGroup says 57%. McKinsey says somewhere between 400 million and 800 million jobs worldwide.

So, from this we can safely conclude that the future is uncertain. And from that premise, some people reason that the only way to approach it is to hedge our bets.

Don't encourage students to limit themselves to a discipline, they say. Encourage everyone to be a capable generalist instead. Teamwork! Emotional intelligence! Public speaking! Creative thinking! That's what will make them adaptable, so that's what we ought to teach. And let students acquire those generic skillsets by following their passions.

What does that look like in practice? It means putting the expectation on teenagers to pick from over 100 different courses available to them in Years 11 and 12. At the same time, training their minds on the importance of graduating with the highest possible ATAR, on the understanding that the higher the number, the wider the choice. And giving them minimal guidance on the discipline-specific knowledge they might actually need to do well in a particular degree. Yes, I am thinking in particular here about the removal of prerequisites from university course guides. And most of all, I am thinking of the messages we give to students about the importance of focus and mastery in maths.

Why do I focus on mathematics? Partly, because it's a skillset that's fundamental to science, to commerce, to economics, to medicine, to engineering, to geography, to architecture, to IT. And partly, because it's the textbook example of why you need to learn things in sequence through hard work, with the guidance of an expert teacher – and the very clear message from schools that it's a priority. You can't just trust your passions to help you meander through it.

So it's particularly vulnerable when we shift the focus from hard content to soft skills. We have the Year 11 and 12 course enrolment data to confirm it. These show a 20-year decline in the proportion of students taking intermediate and advanced maths at Year 12. And it's worse for girls. In 2016, just 7% of female Year 12 students took advanced maths compared with 12% of male students.

We also have a recent study from Western Australia. The heads of the maths departments in 50 high schools were surveyed on the reasons why students were turning away in droves from their more advanced maths classes. And the three stand-out reasons were exactly what I've heard, and I'm sure you've heard, from teachers all over the country. One, it's not required for entry to university. Two, other courses are easier. Three, everyone says you can maximise your ATAR, and thereby your choices, if you just drop down a level in maths.

The logic is beguiling, especially when it's coupled with the message that the future is all about the soft skills. But we also know that the logic is false, because we know what happens to those students who opt for easier courses with more soft skill components in school.

They arrive at university and discover they're in the same unprepared position as that 10-year-old holding a clarinet in her hand for the first time the same day she was enrolled in the school band. They've got to grapple with a discipline like science, or commerce, or architecture, whilst simultaneously trying to fill the maths gap.

And at that stage, what choice do they have? They can drop out of university. They can find another course, after drawing a cross through all the courses involving maths. Or they can struggle through and then find themselves at the end of the degree, competing for a job with students who were better prepared, and thriving from day one.

Consider the data compiled by the University of Sydney, and presented this year. Students who took only elementary maths for the HSC were twice as likely to fail both first-year biology and first-year chemistry, compared with those who opted for intermediate or advanced maths. Another study conducted at Western Sydney University in 2009 looked at first-year university mathematics. Every one of the students who entered with advanced maths passed. Seventy-seven percent of those with only elementary maths failed. That's four out of five, failed.

And yet cohort after cohort of school leavers keeps repeating the pattern, and we continue to allow it, even encourage it. Where is the duty of care?

We have another paper from the University of Sydney, published in 2013. Even at an institution with high ATAR requirements, nine percent of students in science degrees had no mathematics study in senior secondary years, and 17% had only elementary mathematics, with no calculus. Fewer than half of the students in science degrees met the "assumed knowledge" of advanced maths to enrol in the first-year differential calculus unit. And the same study confirmed, once again, that higher levels of mathematics taken for the HSC are strong predictors of success in first-year science, as well as first-year maths.

Now if you were a teenager in the United Kingdom and you wanted to study at one of the elite universities – called the Russell Group – you would open up the group's annual guide. And there you would see, very clearly stated, which subjects are essential for entry into every university course and which are useful. For example, students thinking of engineering would learn that advanced-level maths is essential. Discipline-based courses like maths, English, physics, biology, chemistry, geography and history are identified as "facilitating subjects" – the subjects most likely to be required or preferred for entry. Generic courses like critical thinking and general studies are less important and, quote, "usually better taken only as an extra". So the message is very clear: generic courses cut your choices.

The Russell Group universities understand their place in the education continuum, from primary to secondary to tertiary. They have recognised their responsibility to make it clear to school principals where the priorities need to lie.

Compare that to the lack of guidance sent by Australian universities to students and principals. There was a time when prerequisites were clearly stated in the course guides. And then, about 15 years ago, they mysteriously began to slip away.

"The students of today are no less capable than the students of my generation"

For some universities and some courses, intermediate or advanced mathematics might still be explicitly required, but the number of those institutions and courses has dwindled. Some have replaced "prerequisite" with "assumed knowledge". They are not the same. The word "prerequisite" means that the subject is compulsory; the phrase "assumed knowledge" means the subject is nice to have. There is no possible way in English to interpret them to mean the same.

It is not clear to me why the universities even mention "assumed knowledge" if there is no formal requirement for students to have done the preparatory courses. On the evidence from the University of Sydney, perhaps it might be more accurate to replace the phrase "assumed knowledge" with a longer phrase: "You will not comprehend or pass this course unless you take this subject but the choice is yours."

I believe we can do better. We have to do better than mixed signals. We have to get across that maximising your choices is not the same as maximising your ATAR. And we have to ensure that the ladders to opportunity – the disciplines – are strong.

The students of today are no less capable than the students of my generation. The students in Australia are no less capable than their peers in the United Kingdom. And they will be creative. They will be adaptable. They will run at the future with the confidence that it's theirs to mould. But only if we give them the chance to come out of the glow-worm cave with something distinctive to contribute. So let's teach them every day they're in the classroom, by the content we teach and the things we say. Mastering a discipline is mastering your destiny. And your eyes will be open to the ever-changing opportunities in an extraordinary world.

And May the Force be with you.

12. The Future will Find You

June 18 2018 | Speech to the Australian Science and Mathematics Olympiad teams at Parliament House

In primary school, children feel baffled by that oft-repeated question: what do you want to be when you grow up? By high school, it has turned into real pressure to choose a career. This speech to our Australian Science and Maths Olympiad teams acknowledges them as superheroes, with science and mathematics superpowers and great responsibilities. It encourages them to resist the pressure to choose early and instead focus on studying what interests them, get stuck in, practise and master it. Any limits on where a science career might lead are self-imposed, failures of imagination or courage, or failures of a system that channels students too young into false choices. Right now, hydrogen, a miraculous energy source, is poised, ready to be grasped by savvy entrepreneurs, engineers and creatives. Artificial intelligence is taking off in areas perhaps unimagined, and rather than taking jobs from humans, it is creating jobs for humans.

Usually when I come to Parliament House, it's to meet with the Prime Minister, or to testify before a Senate Committee, or perhaps to speak to an international delegation. I always prepare very carefully for those meetings. In my mind is just one thought: how can I use this little window of time to persuade someone with power to use it wisely?

Students, don't laugh, but I feel exactly the same way speaking to you today. Because you also have power. And what you do with it is immensely important. I know, you're not running the country. You can't vote. And I could be wrong, but I suspect that you don't have access to hundreds of millions of dollars. At least just yet. But at the end of the day, politicians can only make decisions. Science and mathematics, however, make new potential. I think of them as humanity's superpowers. And they're your superpowers.

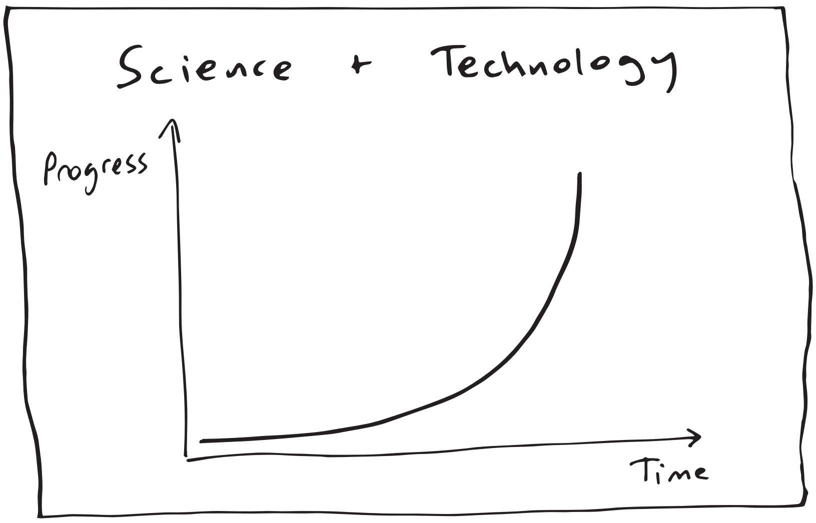
Now I'm sure you won't mind if I give at least a little bit of the credit to your parents and teachers for their support. Parents, you were the first teachers, and you were there every single day, with love and encouragement and support. Teachers, you were there five days a week, setting the bar high, and helping these students to clear it. Between you, you successfully raised these students in an environment where they could thrive.

But students, every one of you had to decide what you would do with that chance. You chose to aim high. You chose to work hard. You made a commitment and you pursued it relentlessly. That's how you developed your superpowers – not by chance, but by choice.

You have made that commitment at a fascinating time. You are citizens of the 21st century – born in it, raised in it. I'm an immigrant, born in the 20th century, and now living here with you in the 21st. So you can believe me when I say that this year, 2018, feels different from all the years I've lived before.

We know that progress in science and technology is an exponential curve. Normally, I have to explain exponential curves, but in this crowd, I know that won't be required. Adults, just try to keep up with the rest of the class.

At first, progress on an exponential curve is so slow that you don't seem to be moving anywhere at all, and then suddenly it's happening impossibly fast. Well, I think we can say that in 2018 we are kicking up that curve. And it's exciting!



It staggers me to think of all the things that were science fiction when I was your age, that still seemed implausible when you were toddlers, but are leaping into reality today.
Let me give you two examples of developments that will define your world, driven by people with your skills.

The first is artificial intelligence, AI. The term was first put forward at an academic conference in 1956, when I was just three years old. But it seemed to go nowhere. A big part of the problem was computers. A great physicist named Richard Feynman sat down in the 1950s and tried to work out how big a computer would need to be, with 1950s technology, to be able to do one simple thing that any toddler can do. Look at a photograph, and recognise a person. He estimated a computer that could do just that one thing would need to be the size of the Pentagon in Washington. And the Pentagon is a building so big that it has its own six postcodes. So you'll understand why the idea of artificial intelligence seemed light years away.

Today, in 2018, Facebook tags your photos by AI and you don't even blink. AI will be an ever-present force in your lives, an entirely new society of thinking, learning beings, making their way in your world. It's going to take a lot of work to teach those robots, and all the humans, to play nice and get along. But you're the ones to do it.

Another thing that seemed like science fiction when I was a student: hydrogen as an energy source. No, I'm not talking about hydrogen fusion. I'm talking about using the electrical energy from solar and wind farms to split water into hydrogen and oxygen, then capturing the hydrogen to use for heating and transport.

And when we use it, well, you of all people know the recipe. Take two atoms of hydrogen, one atom of oxygen, combine to form one molecule of water. There are no carbon dioxide emissions, just water vapour and heat. Hey presto, a miracle fuel. We can make as much of it as we could possibly use, for practically no impact on the planet, for as long as we want. We could turn the global energy market upside-down.

> ***"Stay hungry for new knowledge, truly master your subject matter, never get comfortable in a place where the learning is easy"***

Now politicians and journalists find this all a bit complicated, but you'll say to me, that's not complicated at all. It's just basic chemistry. So why don't we just do it?

Like most things, it comes down to money. When a scientist named John Bockris came up with the idea of doing this on a massive scale, way back in 1972, solar panels were really, really expensive. They were so expensive that the only sensible place to use them was on satellites. But what happened? The world got serious about climate change. With our superpowers – science and maths – we got better and better at harvesting cheap energy from sunshine and wind. The price of solar panels and wind turbines plummeted. Solar panels are about 1000 times cheaper today than they were in the early 1970s.

PHOTO: Australian Science Innovations

And now it's happening. With cheap solar electricity, the hydrogen revolution has started. We're building the hydrogen plants, right here in Australia. We're turning sunshine into money. It's stunning.

But I haven't even mentioned all the other revolutions I keep an eye on. The rise of electric cars. Our soaring ambitions in space. In biology, the new tools that allow us to literally snip life-threatening diseases out of the human genome.

So I hope you wake up every morning fired with the importance of being alive, at this pivotal moment in human history, and imagining all the ways that you could use your superpowers for good.

Now along with superpowers, superheroes have capes. Sadly, we won't be handing out capes today. But you have been presented with some very attractive blazers instead. Think of that blazer as your superhero cape, because in it you will do astonishing things.

And superheroes always start their journeys with a bit of advice. So here's some advice from your Chief Scientist. You're doing exactly what you need to do. Don't fixate now on a specific career. Just keep perfecting your skills. Stay hungry for new knowledge. Truly master your subject matter. Never get comfortable in a place where the learning is easy. Surround yourself with people who challenge you, and inspire you. Keep doing that, and I promise, the future will find you. And you'll be ready when opportunity comes knocking.

It's probably traditional at this point to wish you luck. But you know better than anyone that success isn't luck. It's commitment. You've got all the commitment you need.

So as your Chief Scientist, I'll just say, may the Force be with you.

CHAPTER 03

Higher Education and Research

"Winning the game of faculty"

Chapter 3 | Education and Research

Introduction

Universities, and tertiary education more broadly, are not immune from the changes sweeping the economy – automation, a booming global middle class, and insidious new threats to integrity and quality, especially in the pressure on researchers to publish.

The need to improve research and publication integrity is pressing and has been an enduring preoccupation of my term as Chief Scientist. I have proposed ideas for rewarding quality over quantity in academic publishing, for mandated integrity training, and for a quality assurance process for journals, and I'm pleased to see momentum in these issues around the world.

This isn't the only challenge facing universities. They must also find ways to cater for ever more students and an ever broader range of students, which increasingly means teaching in the digital sphere. Crucially as online plays a greater role, universities must maintain the human element at the forefront and ensure each student receives individual attention.

Quality must also remain the top priority. The job of our education system is not to produce automatons; it is to train innovators, thinkers and specialists.

13. Actions to Advance Research Integrity

June 3 2019 | Opening Keynote Address to the 6th World Conference on Research Integrity in Hong Kong

After co-chairing a roundtable on research integrity and quality with Phil Campbell (former editor of Nature) in 2018, I was fired up and ready to share my three-point plan to clean up the process, remove the incentives to publish at any cost, and improve the accountability of journals. The World Conference on Research Integrity was the perfect forum to share my ideas on how to reduce the inevitable shortcomings of a huge and convoluted system to ensure a better return for effort. Researchers are judged on speed and quantity, and doubted if their output slips to one or two publications a year, no matter how good. This in turn puts pressure on scientists, analysts and statisticians to find significance where there isn't any. And down the line, it means less trust in the academic publication process. The retracted-papers database now numbers 20,000 and that might well be the tip of the iceberg. We can do better.

Looking around the room today, I'm reminded that research truly is a human pursuit; it thrives on face-to-face connections. It's easy to forget that when you're a student and it's late at night and you're the last person left in the lab, again. So, every so often, it's worth pausing to remember just how many people are out there, working hard, gathering data, just like you.

Worldwide, there are more than eight million researchers. Every year, we produce well over a quarter of a million new PhDs. China alone has added more than a million people to its research workforce since 2011. Not all of these researchers will work in academia, but those who do are highly productive. They publish in the order of four million academic journal articles every year, spread across more than 40,000 journals. And all of that traffic is routed through a single critical bridge. The publication process.

Picture that bridge. We know it so well. It's stood there for centuries. And in that time, it's developed from a simple footbridge with a handful of pedestrians into a triple-decker multi-lane high-speed monster freeway. It's still fundamentally sound. The basic structure of peer review is the best we've ever invented. Every day, I see trucks on that bridge carrying outcomes that even Einstein thought would never arrive. The detection of gravitational waves. Devices that can translate brain signals into speech. Atomic clocks that can mark a second with precision in the parts per quintillion.

This great bridge that holds up civilisation has served us well. It is not about to collapse. But it is showing signs of strain.

Start with the fact that there are now more than 20,000 retracted papers in the Retraction Watch database. Does that catch 50% of the times that the quality assurance process failed? Ten percent of the times? We can't say. But we know enough to be concerned.

There was the 2015 analysis, conducted by the US Federal Reserve, of 67 economics papers published in reputable academic journals. Only a third of the findings could be independently replicated.

There was the 2018 analysis of 100 psychology papers, also published in reputable journals. Only two in five could be independently replicated at the level of significant results.

There was the 2015 survey of about 400 statisticians on their interactions with collaborating researchers. Almost half had been asked to report results before the data had been cleaned and validated. A quarter had been asked to remove some of the data. More than 10 had been explicitly directed to falsify the statistical significance; some of them, on more than 10 occasions.

Whatever your field, you'll have your own examples. Put them together, and we have more than enough evidence to conclude that we cannot write off these lapses as the occasional bit of bad driving. The evidence says we haven't built the optimal bridge. The people who pay for the petrol and rely on the safe delivery of the cargo – the taxpayers and governments – are no longer prepared to take us on trust. They want actions to shore up the bridge. So we are gathered at this conference to be the civil engineers.

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Now I'm an engineer by training. I am also Australia's Chief Scientist. And in that capacity I wanted to understand what we could do to strengthen the bridge. I acknowledge, it's an enormous topic. I can't even list all of its dimensions, let alone disentangle them. My focus was practical – what we could do to make a material difference, with a focus on the overarching framework from which other important measures could flow.

So in October last year, I organised a workshop on research quality and the publication process in my office in Canberra. We invited the editor of the Springer-Nature group, Sir Phillip Campbell, along with the heads of our research funding agencies, leaders of ou r research institutions and experts in the field of publications. The full list of names is available on my office website, along with a subsequent article that I published in *Nature*.

I want to share with you today some of the practical measures we considered and how we are pursuing some of them at the national level in Australia. Then, I want to turn to the global infrastructure we would need to consider if we're going to standardise good practices across the world. And in the spirit of fair attribution, let me note that my reflections today are informed by our workshop, but the recommendations are my own.

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So, let me start as our workshop did and as all engineers are trained to do: defining the problem.

The publication bridge is fundamentally sound and it's critical to keep it open. But quality assurance is weakening. We've got trucks arriving with rotten cargo that has to be retracted. Sometimes, but not that often, we've got trucks arriving with contraband cargo and forged transit documents. We've got trucks arriving with useless cargo that nobody wants to purchase. And we've got drivers speeding madly to make as many trips as possible. The traffic backs up at the toll gates, because the good peer reviewers are overloaded. We've got smugglers – predatory publishers – dodging the toll gates entirely. And we've got increasingly frustrated researchers looking for alternatives, jumping off the bridge and into the wild waters of open science below.

> ***"We've got smugglers – predatory publishers – dodging the toll gates entirely and we've got increasingly frustrated researchers looking for alternatives, jumping off the bridge and into the wild waters of open science below"***

We talk constantly about these problems and still they remain. All of the participants in our workshop agreed there are many thought-leadership organisations and there are excellent and widely acknowledged guidelines, but that's not enough when the incentives in the system run the opposite way.

We know from the mining sector, if the safety incentives are set correctly, the safety record dramatically improves. We know the opposite from the finance and banking sectors. If the incentives are set incorrectly, appalling practices prevail. It's exactly the same in research. It doesn't matter how many times we say we want quality over quantity in theory, if we keep rewarding quantity in practice. We've all got to take responsibility for bringing the theory and the practice into line.

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Let's look first at the people directing the trucks and the drivers – our research institutions. For centuries, we've relied on an apprenticeship model of training, just like the way we used to teach our teenagers to drive. Put them in the car with an experienced driver. That made sense in a world where senior researchers were publishing less frequently and had the time to give to perhaps a handful of students. It's reckless in a world where there's much less time to give and many more students wanting to share it.

Even in my day 40 years ago, the pressures were showing. My PhD supervisor, Steve Redman, sat firmly in the school of quality. He averaged about two papers a year. He expected a lot of his students, but he was generous with his time. I realise now just how hard it must have been for Steve to stick to his principles.

As if in confirmation, two months ago, I received an email from one of Steve's contemporaries, recalling that every time he sat on a panel assessing Steve, the beauty of Steve's papers was lost in the clamour about his production rate. That was a senior researcher, an acknowledged superstar, conducting research of the highest quality, with undeniable impact, decades in the past, under constant pressure to accelerate.

Let's just think about the intensity of that pressure on a PhD student and a research supervisor today. How much is that student really going to learn from that supervisor by osmosis? A far more reliable mechanism is explicit instruction – structured, formal teaching in research integrity and professional expectations. Research institutions should make that instruction mandatory, not just in student training programs, but for every one of their existing researchers.

And if we're going to put the time into training, then we should have agreed minimum standards for the modules. As a starting point, accredited research integrity courses should probably cover the material from the Singapore Statement and the Montreal Statement issued after the 2nd and 3rd World Conferences on Research Integrity.

At the same time, we shouldn't expect mentors to be good mentors by instinct. Their institutions should train them in good mentorship, and make that training a condition for any post where they're supervising staff. And instead of judging a senior researcher's performance by the number of students on their books, we should ask for impact statements on, say, two of their former PhDs, at least one of them female – how they were mentored, and what they went on to achieve.

That's not the only change I'd like see in an academic CV. Think for a moment about how a so-called competitive CV looks today – pages and pages and pages of article and authorship credits. No reviewer has the time to evaluate those lists to gauge the quality, so quantity prevails. Imagine how it would look in a system that made quality the focus.

We would opt for a model such as the Rule of Five. Candidates present their best five papers over the past five years, accompanied by a description of the research, its impact and their individual contribution. The exact number of years or papers that institutions opt to consider isn't important. On both counts, it could be anything up to 10. What matters is the emphasis on the significance of the research – and the message it clearly sends.

* * *

How do you shift the behaviour in research institutions, hundreds if not thousands of institutions?

There is a principle known as follow the money. And in this case, the money trail from research institutions leads straight back to the agencies that supply the grants. If we want to motivate change, at scale, then those national granting agencies are key.

My recommendation is that for investigators to be funded by a national granting agency they should be required to prove that they have undertaken an accredited course in research integrity. Without that proof, the grant would fail to get through the first stage of administrative review.

In addition, national granting agencies should evaluate investigators' publication records from a Rule of Five perspective, with total publications and H-indices pushed to the background as secondary considerations.

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Now I acknowledge that I am building on existing ideas. My ambition is for granting agencies to take the leadership role in supporting best quality research beyond the grant itself.

One of those agencies is Australia's National Health and Medical Research Council, or NHMRC, led by Professor Anne Kelso. If my principle is follow the money, Professor Kelso's is "use the power of the funder". And do so thoughtfully, and deliberately, to keep the focus on quality, where it belongs.

Already, we've seen some significant steps forward. The Rule of Five is now in place for some NHMRC grant schemes, and in future, it may well be extended. Further, for two of the major schemes, the impact of the investigator's past research is now an explicit part of their track-record assessment. Impact, be it on knowledge, on health, on the economy, or on the community, is judged on case studies. Not just numbers – explanations.

This is the beginning of the NHMRC's quality agenda, not the end. Professor Kelso is looking comprehensively at the NHMRC's role in supporting high-quality research through all of its processes: policies, guidelines, peer review, the lot.

They will be working with research institutions to recognise and spread good practice. The expectation is clear. Research institutions have to be more explicit in conveying the message to their research staff that quality counts. To verify the commitment, the NHMRC is calling for regular self-assessment by accountable leaders in research institutions, of their institutional policies and reforms.

Another notable example is the Responsible Conduct of Research requirement in the United States. Major granting agencies, including the National Science Foundation and the National Institutes of Health, require every institution that applies for grants to provide appropriate research conduct training.

However, at present, the requirement applies only to postgraduate students and postdoctoral fellows involved in a project. My recommendation to make grant funding conditional on every investigator providing proof they have completed a course in research integrity goes further, in recognition of the fact that we aren't just looking to support a new generation. We're still playing catch-up with the generation before, as well as absorbing researchers from countries where the training isn't required.

There is some progress. For example, I learned this afternoon from the head of the Irish Health Research Board that they have recently implemented a strict requirement that every investigator be able to prove that they have completed a research-integrity training course. And the Wellcome Trust is also implementing broad quality and integrity policies.

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So, as we can see, there are pockets of progress. The bigger challenge remains: how can we scale up and standardise good practice, right across the globe?

Today, we simply lack the systems for a collective approach. In particular, we lack real oversight of journals. We have seen some jurisdictions take action against the worst of the predatory publishers through fraud law. But the reach of those laws is limited. And the standard we want for journals isn't "not criminal". It's "best practice".

Journals are not simply players in a knowledge market. They are knowledge custodians, with all the prestige and privilege that affords. We have to be united in our expectations. If journals are to retain their position as knowledge custodians then they have a responsibility to be more than scrupulous. They also have to be accountable and transparent.

Where exactly a particular journal fits on the continuum between "criminal fraud" and "agreed best practice" is rarely clear. Of course, there are outliers at both ends, but there are tens of thousands of journals in the middle. That's not good for the journals that do commit to best practice, because we've got very few ways to verify their claims. It is extremely good for the journals that don't commit to best practice, because we've got very few ways to save junior researchers and journalists and even policymakers from being duped. To date, it's fair to say that even reputable journals have not welcomed greater scrutiny. But scrutiny doesn't have to come as an imposition.

Let me give you an analogy from my time in industry. I was the founder and CEO of a company called Axon Instruments. We made research instruments, but we also made medical devices – including a product that inserted an electrode three inches deep into human brains during surgery to treat the symptoms of Parkinson's disease.

No-one would purchase that product unless they knew it was safe, so we undertook ISO 9000 certification. This international quality assurance program is like a superset of Good Manufacturing Practices, GMP, required to register products with the FDA in the United States. The ISO 9000 standards are extremely demanding. They apply to the company, the production process and the product itself. Compliance is verified by a combination of internal and external audits. To my surprise, I found that as a manufacturer, those standards became my best friend – because they told my customers that we were selling a trustworthy product. They also kept the market clear of low-quality producers who would first, steal my customers, and second, destroy the whole industry's reputation.

So imagine if we had something equivalent for the publication process. I'm calling it PPQA – Publication Process Quality Assurance. Compliance with PPQA would indicate to researchers, research institutions and granting agencies that the journal followed internationally accepted guidelines. And granting agencies would only consider research that has been published in a PPQA compliant journal when judging applications.

Now I want to be absolutely clear: PPQA is not akin to an impact factor. What I'm talking about is quality assurance, to ensure that journals implement an agreed minimum standard for their publication processes.

We could start with the guidelines developed by organisations like COPE – the Committee on Publication Ethics. Higher levels of PPQA could pick up on the Transparency and Open Promotion guidelines, known as the TOP guidelines, compiled by the Centre for Open Science, or the Reproducibility and Replicability in Science recommendations published this year by the National Academies of Science, Engineering and Medicine. These guidelines form a tremendous body of work, by deeply knowledgeable people, who have reflected on these issues for many years. Let's use it.

Who would audit and accredit that each journal title meets the standards? It could be an existing body like COPE, but they would need funding. It could be a new entity. Or, as happens with the ISO standards, it could be credentialled private companies.

However the audit for accreditation is done, we would require a central global body to hold the list of successful journals, open for checking by granting agencies, institutions, journalists, venture capital funders, everyone. There would obviously be costs, so the inevitable question is who should pay? Turn the question around. Who has a reason to be invested? Journals, for one. Granting agencies, for another. Large philanthropic bodies with an interest in high-quality research, for a third. Some provision would have to be made to ensure that small society journals are not overburdened by audit costs.

All of these questions would require careful deliberation on the model, through discussions involving libraries, publishers, grant agencies and research institutions. And the agreed model that emerged would have to be tested through a pilot to see what works and what might go wrong.

It can't happen without global forums – global bodies with the networks and credibility to speak as the collective voice of science. The International Science Council would be an obvious candidate, as would the Global Research Council.

But we should not continue and extend the good discussions of the past without a matching commitment to action. Since granting agencies provide the keystone research funding, they have the greatest capacity to push for a shift in behaviour. They should set a timetable for the deliberations.

Finally, my recommendation to the granting agencies is that they should turn the results of the deliberations into actions by setting the date after which new papers can only be included in a grant application if they were published in a journal that is shown to comply with PPQA.

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Now, as I acknowledged at the beginning, there are many issues wrapped up in research integrity, and we'll have the opportunity to dive into them this week. But my focus today is on the practical, in the firm conviction that we have a system that is fundamentally sound, but can undoubtedly be improved.

To recap, based on the principle of follow the money, these are my recommendations:

One, granting agencies should make proof of research-integrity training a requirement for applying for a grant, applicable to all investigators listed on the application.

Two, granting agencies should require CVs submitted for grant review to follow the Rule of Five.

Three, granting agencies should only consider new publications from journals that have proven their compliance with PPQA – Publication Process Quality Assurance.

Ambitious, yes, but considering the stakes, I'd say a bit of ambition can be excused.

> ***"The research bridge is every bit as critical because we make life and death decisions on the basis of the data that is trucked across"***

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And I hope this is the spirit that we've all brought to this great global gathering today. Think of that bridge this week. It has served us well but it is creaking under the increased load and evolving driver behaviours. If it were a physical bridge, there'd be no question. We'd fix it. The research bridge is every bit as critical because we make life and death decisions on the basis of the data that is trucked across. It's soldered on to the neural circuits of every engineer. There's always a better way. We can find that better way to do research.

14. Big Questions, Bright Futures

April 17 2018 | Opening Address to the Quality in Postgraduate Research Conference

If I talk about how to make the scientific research system better, a constant concern is that listeners will misinterpret me as saying that science is broken. It is not. We are living in an unparalleled era of scientific progress, which at the end of the year 2020 is apparent in the stunning speed with which multiple COVID-19 vaccines have been developed. My mantra is that there is always a better way, even if we are starting off from a good base. Limited funding, and internecine rivalries are the frustrations of scientific life and we learn to live with them as largely beyond our control. However, there are other aspects of scientific life we can control and that demand our attention. One of those is publishing integrity: the poor behaviour arising around the pressure to publish, the publication bias against null results, and the oxymoron of non-contributing co-authors. As a scientific community, we should devise ways to tackle these problems. PhD students and postdoctoral researchers are the workhorses of our research system and the future leaders who will set the tone and the ambition. This speech to a Quality in Post-Graduate Research conference proposed some touchstone principles to guide this emerging generation of science researchers and leaders. And it urged them to never let frustrations get in the way of the main game. If you can work out how to encase a single nitrogen atom in a carbon molecule to create an atomic clock that will fit in a smart phone, what higher ambition could you have?

One of the best things I've done as Chief Scientist is to sit on the judging panel for the final of the Three Minute Thesis. It's exactly what the name suggests. PhD students get three minutes to explain their thesis. We judge them. That's it.

No costumes. No props. No audio. No animations. No rapping. No singing. It tells you a great deal about PhD students that all of these things are specifically banned in the competition rules. Just a person. On a stage. Talking. About a thesis. One static PowerPoint slide in the background. As raw as it comes.

And the time limit is savagely enforced. How long is three minutes? About the recommended cooking time for a toasted cheese sandwich. For those who think in pages, picture one A4 page in Times New Roman font, size 12, standard margins. It is hard enough to keep it to three minutes when you only know a little about your topic. It is incredibly difficult to know your topic so thoroughly that you can whittle it down without mauling it to death. But that's exactly what every one of the 10 finalists did.

They were fiercely intelligent, highly entertaining and absolutely compelling. As the session wore on I found myself getting almost resentful. Couldn't just one of these presentations be a little less worthy of winning, so it wouldn't be so impossible to judge? But no-one obliged. No, they were determined to be uniformly brilliant. Darn them.

But I suppressed that unworthy and ignoble thought. Alan, you're the Chief Scientist. Just be grateful that these people are advancing knowledge instead of being lawyers billing their clients in three minute blocks. Be grateful that they're doing PhDs.

And that got me thinking about the question that brings us here today. Let's assume that in every generation we get a certain cohort of talented, driven people. In this generation, we know that many of those people will choose to do PhDs. To everyone here today, that is an enormous vote of confidence in the value of what you do, and the integrity with which you do it. And by any measure, it is an enormous investment of our society's potential.
So the question always has to weigh on us. What does it mean to be worthy custodians? This conference will consider that challenge in all its many facets.

Today I want to talk about the foundation – culture and ethos. I want to reflect on what it means to be a 21st century scientist. And in the traditional way, I have framed my thoughts as the advice that I would give to you, the PhD students in the audience today, striving to excel.

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Now I know that advice – unlike funding – is one of the very few things that PhD students tend to get in abundance. This year, in particular, I have seen many articles to the effect that "science is broken" and so the best advice you can give to a person contemplating a PhD is "don't". That won't be my advice.

First, I reject the hypothesis that science is broken. It suggests that science was somehow not broken or at least significantly better at some point in the past. And I just don't see it.

Point me to the period in human history where we had more brilliant people or better technologies for doing science than we do today.

> ***"Point me to the period in human history where we had more brilliant people or better technologies for doing science than we do today"***

I agree, we certainly have our frustrations, like every other profession. But point me to the era when scientists were always courteous to their colleagues, and good at explaining themselves to other people, and were given all the support they could possibly need to pursue rich personal lives alongside stellar academic careers.

Point me to the world were science was open to people of all backgrounds, and science was not misused by people with bad intentions.

Point me to the society where evidence always ruled the public discussion, and every time a scientist spoke the news cycle stopped so that journalists would have the time to pay attention.

> ***"That golden age of science never existed. The only place to find it is in the future. So let's not tell you young scientists that science is broken. Let's encourage you to help us make it better."***

That golden age of science never existed. The only place to find it is in the future. So let's not tell you young scientists that science is broken. Let's encourage you to help us make it better.

The second reason I reject the avoid-at-all-costs school of advice: I see so many ways that science delivers the goods.

Here's just one. One of the most helpful things about being a modern human is satellite navigation. Well, satellite navigation is basically clocks in space – atomic clocks, on satellites, calibrated against the atomic clocks in national standards laboratories. They are very accurate. But if you've tried to navigate with your smartphone in inner-city Sydney, you'll suffer from the problem called multipath interference – signals bouncing between buildings, causing such havoc that poor Google loses it. Reasonably accurate won't be good enough for a city of self-driving cars. Just imagine it.

The solution is to install an atomic clock in every car and smartphone satellite navigation system. But today those clocks are monsters; the best ones fill up rooms. But what if we could shrink atomic clocks down to the size of a computer chip, so we could actually embed them in smart phones?

That's what researchers today are attempting. Instead of trapping an oscillating atom in a giant vacuum chamber, they have trapped it in a tiny atomic cage. A single, spherical molecule of carbon, with 60 atoms, properly named a fullerene, informally known as a buckyball after Buckminster Fuller, the architect who developed the geodesic dome. That single carbon molecule encases a single nitrogen atom and protects it from the environment. The nitrogen atom is stimulated by a laser beam to oscillate at its resonant frequency and presto! A microscopic atomic clock.

Science doing its thing. From an idea put forth by Lord Kelvin in 1879 to the first atomic clock built 70 years later in 1949. And then another 70 years to go from a monster to a molecule. The Space Age and the Information Age bound up in one.

I look at something so astonishing and it seems to me that anyone with a pulse should be excited by the possibilities of science in 2018. Of course people want to do research! They should want to do research! And if they have the passion and the talent to undertake a PhD, then who am I to dissuade them?

So, in that spirit, my advice to the next generation. First principle, you need a relentless commitment to quality. I was lucky to train under a great scientist, Steve Redman. These days we would describe him as unproductive. He published, at most, two or three papers each year. But every one of those papers was deeply considered, included both a hypothesis and supporting data, was meticulously crafted and, as a result, deeply influential. The quality of the papers was simply the mark of the way Steve managed every aspect of his research, right down to building the research equipment. In everything, quality first.

These days the pressures and incentives are very different. We have a whole taxonomy of the ways that systems can encourage or enable good scientists to go wrong:

- HARKing: Hypothesising After Results are Known.
- P-hacking: torturing your data until it screams.
- The file-drawer effect: selectively publishing only the interesting data.
- Pseudo-collaboration: assigning credit where credit is not due, to so-called non-contributing co-authors. Yes, it's an oxymoron, but we all know it's been done.

Only academics could develop such a comprehensive field guide for misbehaviour. They range from the inadvertent to the deliberate. Look up these clever ways to do bad science and know thy enemy because it would be naive to suggest that the pressures aren't real, or that only bad people fall prey to them.

The lesson I take from Steve Redman is that we all need to commit to quality. Consciously. Constantly. It's not necessarily instinctive but it needs to be ingrained. Your PhD training program should teach research quality through specific coursework. In everything, quality first.

* * *

Of course, it's much easier to be relentless if you're doing something you love. And that brings me to the second principle: know your limitations.

I had a very enjoyable time as a young researcher making machines to monitor the electrical activity in – wait for it – the brains of snails. But I couldn't help but notice that my own brain wasn't wired like the brains of the people around me. They got excited about their results. I didn't really care about the results. I just wanted to make the machine for running the experiment. Then make it better. And better again.

So I realised that I could be a deeply unfulfilled scientist, or a passionate engineer making it possible for other scientists to make important discoveries. I chose the latter. But first, I had to define my difference from the scientists around me not as a weakness but, in another context, something that could be a strength.

Today I have no patience for people who tell me that a person with a PhD who starts a company or goes into the public service is a waste of a good academic researcher. The purpose of a PhD is to allow talented people to develop their strengths and choose their direction.

I was lucky, again, to have the guidance of exceptional colleagues and mentors, some of them researchers, some of them with experience in business. But that was the sort of luck I made for myself. I sought out those people whose advice I knew I could trust.

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That brings me to principle three, be a generous listener and sharer. We have told ourselves for aeons that science has a problem with silos.

As Chief Scientist, I have a bird's-eye perspective. I've met scientists from the same university, the same department, sometimes even the same corridor, who have simply never spoken. So, much of my work is matchmaking.

But I have the benefit of distance. From a distance, you can often see the patterns that are hidden from the people working up close. I know that for PhD students in particular, the research life can be isolating, anxious and all-absorbing. We need to encourage the habit of conversation, not as a sideline, but as simply what good scientists do. That doesn't mean it happens by default. Like committing to quality, it has to be a conscious choice. So go to seminars and speak to the attendees. Walk the corridors and see not just what is there, but who is there. The pay-off for a young researcher who makes that commitment is good advice – and just as importantly, new opportunities.

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Principle four, be open to opportunities. The Nobel Laureate Richard Feynman had a nugget of wisdom that he would hand out freely to young researchers. Come up with a list of your 12 favourite problems. Keep them constantly in your mind, present, but dormant. Then, every time you come across a new research tool, or an interesting discovery, test it against your 12 problems and see whether it helps. It's amazing, he said, how many people will marvel and say "he's a genius!" if you just look methodically for opportunities. Feynman's advice is an application of an old maxim that I took with me when I left Australia to start my company Axon Instruments in California: chance comes to the prepared mind.

Dr Finkel with (then) Chief of Staff Anne-Marie Lansdown
PHOTO: SugaCoatIt

These days I prepare my mind to look for people with interesting stories. And it's amazing. I never meet a person who hasn't got one! In the last month alone, I've met with the founders of Gilmour Space. One was a banker for 20 years. The other was a marketing graduate. Now they've raised $5 million to launch small satellites into low earth orbit using the world's largest single-port hybrid rocket engine.

I met with the founders of Tritium. They got their start in the World University Solar Car Challenge. Now they employ 130 people making fast chargers for electric vehicles, and those chargers line highways all over the world.

I spoke at a forum on the same day as Dr Catherine Ball. She completed a PhD in spatial ecology. Now she's a leader for the global "drones for good" movement, focused on the use of drones for humanitarian work. She's the co-founder of the first global drone conference, and in her spare time she's on a mission to give 100,000 women and girls in Australia the opportunity to fly a drone by 2020.

It seems to me that very few people get to interesting places by doing conventional things. No, they get there on the trail of opportunity.

So four pieces of advice:

1. Relentless commitment to quality
2. Know your limitations
3. Be a generous listener and sharer
4. Be open to opportunity

Which brings me to the opportunity presented by this conference. And now, I'm speaking to everyone here today. You're here because you care about research. So let's use this conference to think about how we can all inch science closer to that future golden age.

And I'm going to follow my own advice, and take a cue from Richard Feynman. In that spirit, I'm setting out a few big questions. And I'm asking everyone here to test out the ideas and approaches you encounter over the next few days to see whether they advance us any further in solving them. So here, in no particular order, are some of the things that I've been thinking about.

The future of the scientific paper

Last week, The Atlantic magazine published a provocative essay: The Scientific Paper Is Obsolete. It's done great things since it was developed in the 1600s. And today we could certainly say that production is booming. But the peer review system is critically overloaded. Page charges are high, and so the critically important methods section is left out. Alternatives pop up overnight because the barriers to entry are low. And the irony is, we're working so hard to generate papers, we don't have time to read anybody else's.

One has to ask, have we hit Peak Paper? My tentative response is no. The scientific paper has endured for a reason, and it still holds. It's an efficient way to structure and communicate information. But what do you think? Will we still be publishing papers in 2050? And how else could we do it?

The pressure to publish

I spoke of my 'unproductive' supervisor Steve Redman. I think we would all agree that publishing a few articles a year is the ideal. Authors could invest more time in their papers, and peer reviewers could invest more time in their critiques. In the real world, we know that the incentives often skew the other way.

But where do you intervene to break the cycle? I recently saw a radical suggestion: a lifetime word limit for researchers. I suspect it would be very difficult to enforce. But what about a variation: change the focus from publications to CVs.

For starters, let's contemplate a rule that you can only list a maximum of five papers for any given year when applying for grants or promotions. And your CV would have to list retractions, with an explanation. And, on the recommendation of Jeffrey Flier, the former Dean of the Harvard Medical School, candidates for promotion would have to critically assess their own work, including unanswered questions, controversies and uncertainties. One to consider.

Better incentives for thankless work

Should we have dedicated funding for replication studies? Should we consider awards for high-quality studies that yield negative results and don't confirm a hypothesis or previous finding? It's been tried in some disciplines. Could it be done at scale?

Predatory journals

If journals are the gatekeepers, then predatory journals are the termites that eat the gates and make the community question the integrity of the structure. How do we fight back? And how do we arm people in the community who aren't scientists, and don't know anything about impact factors and journal rankings and editorial standards, to recognise quality?

Is there an analogy to Fairtrade coffee: a stamp that consumers can look for on the product that demonstrates it complies with a certain standard? Could we promote an "ethical journal" stamp?

Artificial intelligence

Bloomberg reports that there are now five ways to command a multi-year seven-figure salary. It used to be four: CEO, banker, celebrity entertainer, professional athlete. The recently added fifth is "a person with a PhD in artificial intelligence". This is the AI century. Like all great waves in technology, it breaks on researchers first. Time and time again, you get the future – you make the future – before it sweeps over everyone else.

But what does it mean for research training? What roles that scientists do today, will robots do tomorrow? What roles that no-one can do today will become possible, with the power of humans and robots combined? They are fascinating questions. And ones that lend themselves to many wonderful, insightful PhDs. Is there one in your future with your name on it?

* * *

But I am well beyond the three-minute mark. So let me conclude with the immortal words of the immortal doctor – by which I mean, of course, Doctor Who: "A straight line may be the shortest distance between two points, but it is by no means the most interesting." I say, enjoy the conference – and keep it interesting.

15. Winning the Game of Faculty

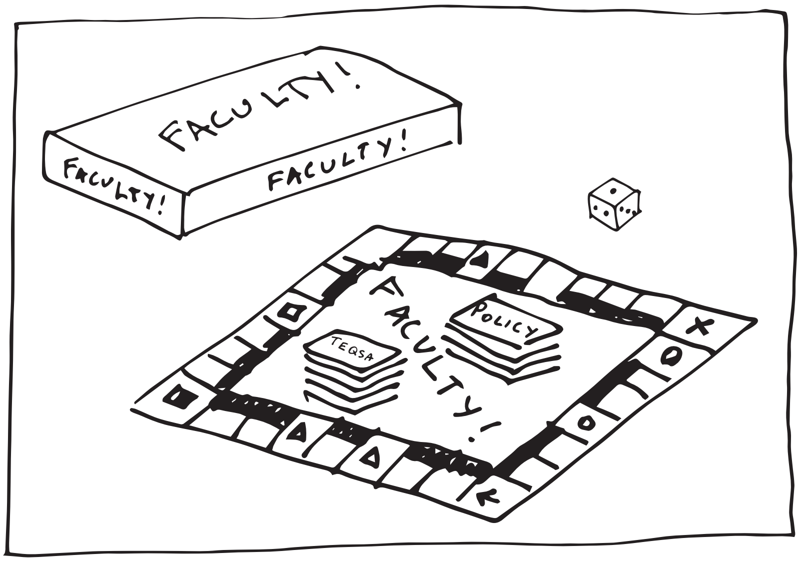
March 1 2018 | Dinner Address to the Universities Australia Higher Education Conference

I have long regarded Australia's universities as among the country's best innovators, adapting to change with impressive alacrity. This speech, to a Universities Australia higher education conference sets out a 10-point plan to keep Australia's tertiary sector at the forefront, including investing in national research facilities, embracing commercialisation and research links with businesses, working towards longer term funding plans with government, and reforming vocational education. Dinner speeches are the hardest. You want to make some important points, but your audience has worked a long day, and has just consumed cocktails, canapes, wine and a main course. Your enemy is postprandial narcolepsy lurking within each and every one of them. In this case, a variation of the board game Monopoly engaged their attention. They were all eager to win.

I recently came across a board game called Power Grid. It's like Monopoly for electricity. Each player represents an energy company that bids for power plants, and then competes to supply the market. You win if you connect the most cities.

Before you ask, yes, this board game was designed by Germans. But it's also available in English, French, Polish, Italian, Spanish, Dutch, Chinese, Korean and Portuguese! It's sold hundreds of thousands of copies. Everyone loves playing energy policy! And I thought, of course they do. What sector has more intense human drama than energy? Which sector calls for such a rich combination of tactics and strategy? Where could you possibly find so many wonderful, detailed, positively Germanic rules, and pages and pages of scorecards, with complicated and occasionally incompatible objectives?

And then I remembered. Forget energy. What we need is a board game about building and running a university. We could call it "Bricks… Bricks and Mortarboard". Or Dungeons and Dragons. No, already taken. How about "Game of Sandstones". Sorry! "Faculty". Let's just call it Faculty.



Here's how I imagine Faculty would be played. Every player is a vice-chancellor. You start the game with an allocation of land and some funds that you can spend on various things: research facilities, big-name scientists, campus amenities, you name it.

You win by driving your institution up the ranks for research excellence, student satisfaction, graduate outcomes, staff diversity, community engagement, environmental sustainability, industry partnerships, workplace safety, fiscal responsibility. And every now and then, without warning, new rankings will be added to the list. As a player, all you have to do is keep all of those goals in mind, all the time.

Every round, to make more money, you have to enrol more students. But don't forget, you have to make them happy *and* employable. And you can't do that at the expense of your research facilities, because then your ranking would fall. Which would cause your student numbers to slide. Which would eat into your budget. And you'd be back at square one, building up your reputation all over again.

Can you play by house rules? No. That's why we have a whole stack of TEQSA cards – to keep up the standards. Is there a Get Out of Jail Free card? No, of course not. This is higher education. Nobody gets anything for free. Sorry, I mean nobody ever does anything illegal. And no, there's no Free Parking, either!

But there would definitely be wildcards. Oh yes, there would definitely be wildcards. We'll call them Policy cards. Roll the dice. Land on a Policy card square and turn the top card from the deck. A train line is built to your campus – double your student intake. Turn another – an election is called; spin the wheel of fate! Turn another – you have won second prize in a beauty contest. Sorry, wrong game. You have received a rating of 5 in ERA. Boost those rankings!

> ***"Is there a Get Out of Jail Free card? No, of course not. This is higher education. Nobody gets anything for free."***

See, it would be fun. But I hope it would also be educational – and a reminder that the success of our universities is not a matter of chance. If it's a game, it's a game of strategy, one that the people in this room have played extraordinarily well.

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There was a time when I thought that universities were racing towards extinction. I gave a speech in 2008 about how the virtual world called Second Life was turning learning inside out. Bricks and mortar campuses would close. Education would move online. One university to rule them all. The end of a 1000-year dream run.

But we said something similar about board games. They're even older than universities. We've been playing them for more than 5000 years. And what do you know? In 2018, it turns out that board games are booming, especially in Germany. And the people who are buying them are the kids who grew up surgically attached to their smartphones. I promise, there are students right now, in colleges on your campuses, playing board games.

The same basic truth about human beings keeps universities and board games going strong. We thrive on human connection. Playing a game online and playing across a table are not the same experience.

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It's true, our universities are changing. But that's because the people in this room are changing them – not reluctantly, but strategically, with a vision for making them better. I don't see a sector being dragged backwards into the modern world. I see a sector inventing the modern world, and reinventing itself. I've said it before, and I'll say it again here tonight: our universities are among the best-run innovation projects in the country.

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That doesn't mean that every experiment we've tried has succeeded. Even Grand Masters have to reconsider their tactics from time to time.

If there's one thing that I hear more often than anything else, it's this: bring back mathematics prerequisites for courses where a knowledge of mathematics is required. I hear it from teachers, I hear it from parents, I hear it from employers and yes, I even hear it from your lecturers.

PHOTO: Universities Australia

A close-run second would be: let's have a better conversation about the role of the ATAR. We in this room know the ATAR is a tool. Students treat the ATAR as the goal. We see the ATAR as a means to select students. Students see the ATAR as a reason to choose subjects that will boost their score, rather than the advanced and appropriate subjects that will underpin their future studies.

Ask any Year 10 student: how do you boost your ATAR? You drop down a level in maths. So we end up with an absurd situation. Students pick easy maths because they want to get the ATAR for engineering. They get into engineering and they struggle because the maths isn't easy.

The burden should not have to fall on your lecturers to retrofit fundamental knowledge and skills through bridging courses that, in any event, are no substitute for years of learning at school.

The system endorses the ATAR for the same reason that the people who make board games put an age range on the box – so buyers can work out whether this game is right for them. But the analogy is failing. So what should we do, as a sector, to help students see beyond the ATAR to the skills they need for the course? It is time to transform, not defend.

* * *

But enough about tactics. Let's think about the Faculty game. How could we change it, as a country, to make it easier for Australia to win? Right. I've got 10 recommendations. Turn over the egg timer. Feel free to shout "bingo" if you agree.

1. Pre-reading. Everyone in Canberra and probably the country should read or watch Professor Margaret Gardner's National Press Club speech.

2. Upgrade the pieces. I'm talking about a long term strategic commitment to our national research facilities – the planning, the building, the maintenance and the graceful exit.

3. Get a better scorecard. In particular, do something about the way that the statistics on university collaboration with industry are reported.

I can't say this delicately. The global rankings today are flawed. The claim that we are the worst of the worst in the OECD is wrong. Start with the 16,000 businesses that Margaret told us today have formal collaborations with Australian universities. That number is 30 times higher than the collaborations we last reported to the OECD. Assume that five years ago, when we made that report, we were half as good as we are now. For one thing, we would have made truly astonishing progress. But our reporting would still have been out by a factor of 15. It defies belief. We haven't even accounted for businesses collaborating with the CSIRO. Or ANSTO. Or the medical research institutes.

PHOTO: Universities Australia

What is going on? It turns out that the collaboration rankings in the OECD are determined by business surveys, and we do ours differently than the Europeans. Efforts are made to align the two. But because of methodological differences, we still come off very much the worse. Should we collaborate more? Yes. Fifty percent more sounds good. Well done to Universities Australia for upping the ante. But let's also get better at providing the score to the OECD.

4. On the topic of scorecards, let's welcome the ARC impact and engagement metric. It was carefully designed following a proof of concept trial and pilot. Like it or not, society has a right to know the benefits it reaps from its investment.

5. Community Chest. Let's support Innovation and Science Australia's call for a fund to assist university commercialisation activities.

6. On that subject, let's also back Innovation and Science Australia's recommendation for a collaboration premium as part of the Research and Development Tax Incentive – an extra incentive for companies who do their R&D in partnership with you.

Margaret issued the clarion call to business today, and not just a call, but a business case, a phone book and a primer. So no excuses. To all the business leaders out there, we know you've all got phones.

7. Long term commitments from the banker. Wouldn't it be nice if every time you passed Go, you could be confident that you would receive that $200, so you could plan your next investments with a view to the short term needs as well as the longer term horizon. You could bang that hotel down on Park Lane like you meant it.

I remember a conversation I had with a senior policy bureaucrat in France when I led an innovation delegation there last year. We were talking about our experiences with long term programs. When I asked how long the funding for their Cluster Program would last, he literally did not understand my question. It turns out that their funding is indefinite, with a strategic review every four or five years. I literally did not understand his answer. Instead of funding their programs for four years and making a decision towards the end of the period to either renew or terminate, the funding continues forever – unless the decision is made to terminate following a strategic review. Once I understood, I fainted with envy.

8. Threats. University leadership responds to threats like a vacuum cleaner to dust. Bring it on. Books, radio, television, video, the internet, search engines – they've all been hoovered into day to day operations. MOOCs? Deliver and incorporate. Micro credentials? Deliver and compete.

9. The relationship with the VET sector. I've had my eyes opened. In recent months I've been talking to companies about their programs in schools. They all want to talk to me about VET. They say it's critical. They mean critical in both senses – critical as in "vital", and critical as in "extremely unwell". A cynic might say that VET's loss is university's gain. In a narrow sense it might be true, but as far as the nation is concerned, it's definitely not as it should be. VET and universities have complementary strengths. So let's play to win, as Higher Education United.

10. Engage in a national discussion, an aspirational discussion. How about this: in the game of Faculty, if you pick the Policy card that says "engage in a national discussion", and you follow the instructions, every player receives a $5 million dollar endowment from a philanthropic foundation, with absolutely no strings attached.

* * *

With new rules like these, Faculty would be a game that we could play with confidence. Less trauma every time you unfold the top card from the Policy deck. More confidence every time you turn the top card from the TEQSA deck.

Faculty might not be on the shelves in time for Christmas. But I have every confidence you, the leaders in this room, will continue to play the real game with vision, with teamwork and with strategy. We play the game for good reason.

The first and arguably greatest neuroscientist, Ramón y Cajal, said his father taught him that "ignorance was the greatest of all misfortunes, and teaching the most noble of all duties". So here's to all the Grand Masters of Higher Education gathered in the Great Hall of Parliament House tonight. And let's keep the real game going for another millennium.

16. Getting Ahead

October 25 2017 | Annual Merson Neuroscience Lecture at the Queensland Brain Institute

As a neuroscientist, I have watched brain research in action for more than 40 years. It is complex, sophisticated, exquisitely slow, and astonishing in its potential. We're on the cusp of some very significant breakthroughs – the Stentrode that will allow patients with paralysis to control devices with signals from their brains; devices to control pain by blocking signals in the spinal cord; replicating a neural network on a computer chip. But at the same time, brain diseases remain painfully intractable, with limited progress made in treating devasting illnesses such as depression, brain tumours, dementia and motor neurone disease. Europe, China and the United States are pouring billions into their human brain projects. Australia is doing some top research in this field and must now up the ante with serious investment. In this lecture to the Queensland Brain Institute, I was able to tap into my personal experience in neuroscience research and equipment design, and extrapolate to the breakthroughs that will unfold in future years.

Let me begin tonight by flexing our brains. We're going to travel back in time, by the power of thought, to Egypt, 2000 BC. You're an investor in a pyramid scheme. You've gone to inspect the progress on the construction site when suddenly, a careless slave dislodges a chunk of sandstone that hurtles from 100 metres above and clonks you square in the head. You open your eyes and you're lying in the sand, staring at the clouds, and bleeding profusely. It's ugly.

But you're in luck! You're wealthy. So your slaves pick you up, dust you off and carry you for treatment by the most expensive doctors. The doctors immediately consult the medical literature – or in this case, the medical hieroglyphics. It's a document we can still read today, called the Edwin Smith Papyrus. What treatment does it recommend?

First, the diagnosis. The doctors will poke around with their hands and watch to see if you shudder or start leaking any interesting fluids. Then, the treatment. They will fetch a nice cow, and slaughter it, cutting out a juicy steak to slap on your head to staunch the blood. They'll get some honey and smear your head. They'll wrap you in linen, pour milk in both your ears and hand you the bill. And probably barbecue the rest of the cow. Anyone who has reservations about the benefits of modern medicine is welcome to try the good old-fashioned way at home.

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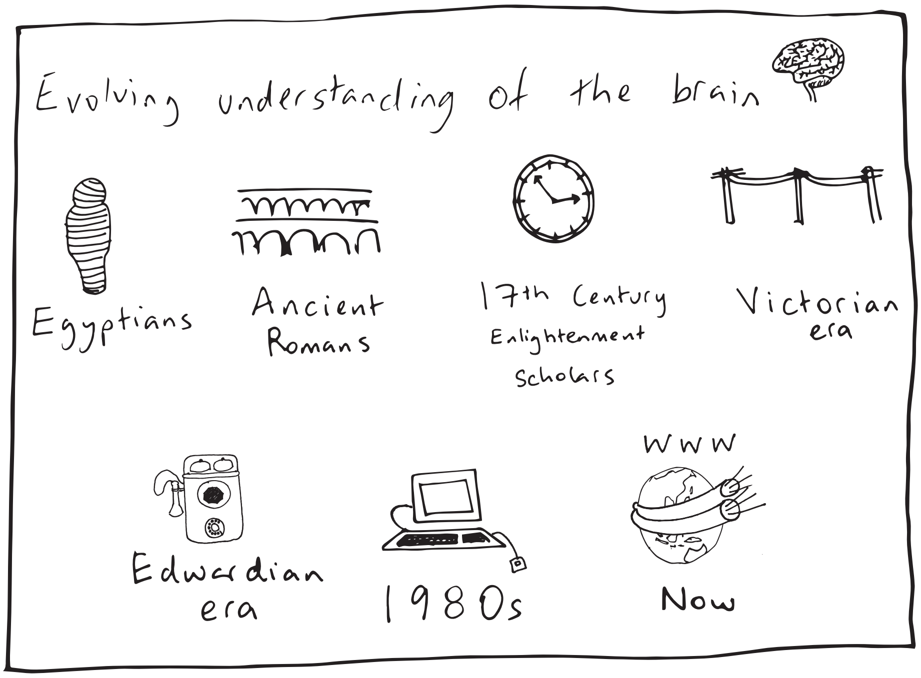

But we shouldn't think too badly of the Ancient Egyptians. At least they had a grasp of basic anatomy and a knack for cutting up corpses. For the next 4000 years, that was about as sophisticated as it got. The secrets of the brain were locked so firmly in our skulls that we could learn next to nothing about its structures, its functions or its disorders. You can only record what your technology actually allows you to see. And whatever you see, you have to try to interpret.

The Ancient Romans thought of the brain in terms of their most advanced technology – aqueducts and waterways. Enlightenment scholars in the 17th century thought of it as a clock.

The Victorians compared it to electricity. The Edwardians compared it to the telephone network. At university, I was taught to imagine it as a computer. Today, we think of the brain as something akin to the internet – a web of complex pathways and interconnections.

I'm reminded of the saying about economic models. All are wrong, some are helpful. The same is true of metaphors. They inch us closer to the truth. For every useful metaphor, of course, we came up with a lot of bad ones, and bad theories to match.

Dualism: the pineal gland is the conveyor belt between the brain and the soul. Phrenology: you can spot a criminal by the shape of the head. Parapsychology: stare at a spoon, and you can bend it with the force of your mind rays. Nonsense.

The father of modern physics, Isaac Newton, said that he stood on the shoulders of giants. The father of modern neuroscience was Ramón y Cajal. He found himself standing in a quagmire of crackpots. He was a nice man so he put it more kindly. He called it "my forgotten corner", so dark it didn't have a name. But in that corner, in the late 19th century, he found a window. And he opened it with drawings of the brain so meticulous, so accurate and so beautiful that we still publish them in textbooks today. Art books, and science books.

> ***"The father of modern neuroscience was Ramón y Cajal - he found himself standing in a quagmire of crackpots"***

We looked through that window – we saw with his eyes – and we glimpsed for the first time the awesome scope of the final frontier in science. Not the distant stars. Not the deep oceans. The brain. The human brain. Ourselves. And from that point on, there would be no turning back.

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Now let's jump forward to Australia, 2017. This time you're an ordinary person. In a good way! But something's wrong. Your speech is slurred. Your vision is blurry. You feel dizzy. So you get yourself to the hospital for an emergency CT or MRI. They find a blood-clot in your brain. Yes, it's a stroke. They can give you clot-busting drugs that dissolve the obstruction. Or if they can't, they'll insert a catheter through an artery in your groin and feed it to your brain to physically remove the clot. All this, in less time than it would take a doctor in Ancient Egypt to fetch a cow.

You'll be transferred to a stroke unit for monitoring and follow-up care. You might find all of these technologies astonishing. But, to the doctors, they are simply routine – the standard care, for the average patient, on a typical day, in a nation like ours. To be astonished, they say, look at what comes next, and not just in the treatment of stroke, but across the full breadth of that final frontier.

Imagine if we could help people suffering from chronic pain, not with addictive painkillers, but with an implant in the lower back that sends an electric current into the spinal cord nerves to mask the pain, and then records the signals from the nerves, in real time, so the current can be fine-tuned to deliver maximum relief.

Imagine if we could install a pacemaker in the brain, for conditions like Parkinson's disease, blocking errant signals from faulty brain cells, and reducing tremors, enabling mobility, perhaps even restoring speech.

Imagine if we could learn from the way the brain collects and stores and processes enormous volumes of information, consuming a tiny amount of energy, in such a little space. What if we could replicate something as intricate as a neural network in silicon, on a computer chip?

All of those technologies are not just plausible; they are in production. It is an extraordinary moment to witness – the early pay-off on decades and decades of painstaking work to image the brain, to study its mechanisms, to learn from its secrets.

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About 20 years ago, I was sitting in the audience listening to the presenters at a neuroscience symposium. Hearing about the breakthroughs and the new research avenues that they opened, I said to myself that we probably knew about one percent of all there is to know about the brain.

Every year, I repeat the exercise. Every year, there's an avalanche of discoveries. And every year, I'm still saying exactly the same thing: now we know about one percent of all there is to know about the brain. The more we learn, the more complex the puzzle appears.

And so we have extraordinary advances in science, on the one hand. And on the other hand, next to no traction in the metrics that dominate our lives.

What is the leading cause of death for Australian women? Dementia. It overtook heart disease this year. We're getting much better at treating heart disease. We're not getting much better at treating dementia.

What is the average life expectancy of a person diagnosed with motor neurone disease? Two-and-a-half years. There is no known cure, and no effective treatment.

What is the annual cost of depression to Australia? About $13 billion. The human toll is infinitely worse. Suicide is now the leading cause of death amongst young Australians.

I lost a dear friend, the great composer Allan Zavod, to glioblastoma late last year. The survival rates for brain cancer have not improved in the last three decades.

Is there a person in this room who hasn't longed desperately for answers, answers that with every step forward, just slipped further away? But slowly, slowly, we are bringing the insights together, from molecular neuroscience, to cellular neuroscience, to systems neuroscience, to behavioural neuroscience. We are seeing that first wave of truly breakthrough therapies. And so I am now prepared to say it: we are entering the era of translation.

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The story can be told in just one device, the Stentrode. And I have some tiny attachment to this story, at the start.

At an unspecified time in the past, I completed my PhD, patch-clamping snail brains to measure the electrical activity between neurons. Back then, it was extremely hard going. The tools I needed were not commercially available. I had to engineer them myself. It was the start of my company, Axon Instruments, but that's another story.

And I was only one small part of what followed, a whole new generation of experimental tools, capturing progress in computing and genetics and machine learning and bio-fabrication, and so much more. With these tools, scientists were able to not just record electrical activity, but to translate it into computer code.

The next step was to translate the code back into a signal, a signal that would prompt a device to move. Think about it. We could pick up electrical frequencies, convert them to code and then into an action. We could control a device by controlling our thoughts. What might that device be? What device would we want to literally control with thought? How about an exoskeleton so a paralysed person could walk?

Enter the Stentrode, a device the size of a matchstick. It's an array of electrodes that can be inserted by a catheter into a blood vessel in the middle of the brain. Once the Stentrode is expanded, the blood continues to flow and the electrodes pick up the electrical signals from the adjacent motor cortex. Feed those brain signals to an external computer. Interpret them to drive the motors of a bionic limb. Mobility in a matchstick.

And here I come into the story again, from the sidelines. The inventor Tom Oxley approached me in 2014, when I was Chancellor of Monash University. All I could offer him was enthusiastic encouragement. He didn't need much, and since that time I have followed his progress with admiration.

Did the world imagine the Stentrode when I was patch-clamping snails? No. But everything that followed – the global investment in basic research, in building better research infrastructure, in training up a generation of researchers – all of it is contained in that matchstick.

* * *

Let me pause there, because I'm conscious I've introduced two words – investment and infrastructure. One of the first things I discovered as Chief Scientist is that those words are deeply interesting to a lot of people. It's been put to me, for example, that the brain consumes about 20% of the body's energy. On that premise, brain research should get about 20% of all the available funds. It's certainly worth a try.

But on any measure, it is fair to say that the brain is already in the ascendant. The vital signs are strong. We can measure it in blockbuster programs. The Europeans have the 10-year Human Brain Project, one of the two largest scientific projects the EU has ever funded. China has the 15-year China Brain Project, announced last year. The United States has the BRAIN Initiative: that's B-R-A-I-N, in capital letters; kicked off with more than $US100 million from President Obama, and proposed investment in the order of $US5 billion.

Along with the public funds, there's the corporate interest, with ventures like Neuralink, from the man who brought you Tesla and SpaceX, and the Allen Institute, from the co-founder of Microsoft.

But perhaps the best measure of the health of the field is the green shoots – the influx of young researchers, amongst them the best and brightest of their generation. When I returned to Australia from the United States I wanted to do something to foster that generation in Australia. I established the Australian Course in Advanced Neuroscience, known as ACAN, an annual three-week residential program that brings the cream of the early researchers together with experts working at the absolute edge of the field. Strongly supported by the whole of the Australian and New Zealand neuroscience community, with intensive support from UQ and QBI, ACAN has been operating now for 13 years. If the ACAN alumni are the future, then Ramón y Cajal would be proud.

* * *

So what next? What next for Australia? What should our contribution be? We could start with a quick head scan. If we think of the Australian brain research community as a brain – and we're all neuroanatomists here, or at least passable amateurs – we have a healthy cerebral cortex.

We have the capacity for genuinely world-leading research, with particular strengths in imaging. The National Imaging Facility, for example, is gold-standard, and one of the few research infrastructures able to integrate the insights from the most advanced high-resolution scanners with the broader evidence from conventional imaging tools in widespread use.

At the local level, early on in my term as Chancellor at Monash University I was amazed to discover that we had just installed a "300,000 electron-volt double-aberration corrected Titan transmission electron microscope". Eight years later, we had installed a more modestly named but more suitable for biology "cryo-electron microscope", and our scientists were seeing the details of biological proteins that previously they could only imagine. This year, Swiss, German and Scottish scientists received the Nobel Prize for the invention of cryo-electron microscopy.

> ***"Brain research to the Australian people is the hope of a life-changing miracle – a treatment for autism, an answer for dementia, eyes to see, legs to dance"***

So we have the tools

So we have the tools, and we've also got the skills and reputation. Sticking with the brain analogy, we could call that the limbic system. We have highly competitive research institutions, including the Queensland Brain Institute, and the biomedical cluster in my home town of Melbourne. Just as important as the components are the connections. We've got them. We're small enough to be a networked community, and large enough to be globally relevant. We have a promising blood supply, in the Medical Research Future Fund, and the Biomedical Translation Fund. And now we have the equivalent of cranial nerves, in the Australian Brain Alliance – relaying the messages from the brain research community to the rest of the body.

So yes, it's a healthy brain. The synapses are firing. We want to put that organ to work. It is not for me to define what the mission for the brain alliance should be. But I take a keen interest in its progress, and I seem to be in the habit of giving advice.

Let me offer three thoughts about the way forward. First, set an ambitious goal. And by ambitious, I mean realistic for scientists and inspiring for everyday people. Both are important. A goal that is ambitious to the point of absurdity is useless – we set out expecting to fail, and we forgive ourselves for falling short. A goal that is hard but achievable is motivating – credible to our peers, credible to investors and credible to government. But it can't just be credible, it should also be exciting. Excitement is the magic that makes the credible into the truly compelling.

Brain research to the Australian people is the hope of a life-changing miracle – a treatment for autism, an answer for dementia, eyes to see, legs to dance. Things we can be proud to call Australian. At every conference I attend, someone is sure to mention the Big Three. Stump-jump plough. Black box recorder. Cochlear implant. Those who are more up to date will mention Gardasil. Yes, I know, they're all great. But my dream is to go to a conference and hear about the next cochlear in neuroscience: the iconic achievement that makes Australians proud. Let's set out to create it.

Second, put the focus on transformational research technology. Call me an engineer. I'll wear it. But when it comes to neurotechnology, I'm not alone. There is a very clear and very deliberate focus on technologies in both the American and European agendas. The Americans front-end it in the full name for their capital-letters BRAIN Initiative: Brain Research through Advancing Innovative Neurotechnologies. They back-end it in the program's goals: safe and effective medical devices for consumers. Technology is the alpha and the omega – the driver and the goal. The ambition of that agenda is truly remarkable.

Last year I learned of a project in DARPA, the advanced projects wing of the US military. They want to build a brain-machine interface with the capacity to bi-directionally communicate clearly and individually with up to a million neurons. Communicating with a single neuron is insanely difficult. Communicating with a million single neurons, at the same time, is a million times insane – at least on the face of it. But what extraordinary breakthroughs could be made in the attempt!

And what extraordinary opportunities might arise for breakthrough thinkers, like the members of Robert Kapsa's team whom I met at St Vincent's Medical Research Institute in Melbourne. They are well aware that the inability of axons to adhere to metal electrode surfaces is the limiting factor for connecting single neurons to electronic circuits. It's like trying to stick gold on to aluminium. Ask an engineer, it doesn't work. Unless you coat the aluminium with an intermediate layer of nickel, then plate the gold to the nickel. And you can do something similar with axons and electrodes. The prototype I saw at St Vincent's uses an intermediate layer of muscle cells. Muscle cells stick to metal where neurons won't. So let the muscles attract the axons to form neuromuscular junctions and presto, a stable connection to individual neurons might be possible! A breakthrough idea, a transformational tool.

The physicist Dyson Freeman had a maxim: "New directions in science are launched by new tools more often than by new concepts." Ask any neuroscientist, he was dead right.

I think, for example, of the MRI, magnetic resonance imaging. This year, in July, we marked 40 years since the first human MRI scan. It was supposed to happen seven weeks earlier, in May, but the first attempt failed. The subject was the lead inventor. And he had a little too much body fat for his own device to work. Fetch a grad student! And luckily for science, and the grad student, a crude image was obtained, a 2D view of the heart and lungs, reconstructed with colour pencils from a mere 100 data points.

That image was only possible because a physicist named Isidor Rabi wanted to study the nuclear spin of sodium back in the 1930s, and was too lazy to put up for long with the cumbersome tools provided. So he worked incredibly hard to make them better. He observed the quantum phenomenon of nuclear magnetic resonance in 1937, with a tool that soon became standard in chemistry and physics. It took another pioneer to think through its potential applications in the life sciences, and, in time, to the study of the brain.

Thirty years ago it was a challenge to take one low-resolution image in a session. Now we can take high-resolution images every second. At first we could just see grey matter, the cell bodies. Now differential tractography MRI shows us the white matter – the connections across the brain – and it's revolutionised our understanding of cerebral networks. To start, we just imaged structure. Then, we imaged the functional areas of the brain. Now, we're imaging thinking. And we couldn't imagine neuroscience without it.

So it is technology that shifts the horizon of possibility for science. But of course, that's not all. When the horizon shifts for science, it shifts for society as well. Today the MRI is a standard part of medicine, a household name, with considerably more than a million scans performed across the world every week. The technology has come so far that we can now do therapeutic ultrasound, guided by real-time MRI, to focus on a tumour, and destroy it. Extraordinary.

The lesson I take is that we can't expect to be competitive in science or innovation if we leave the toolmaking to other people. I speak from experience, having deliberately given up an academic research career to make scientific instruments that helped the research careers of thousands of neuroscientists. We need to be connected to the big global missions, in the thick of the action. And we need to be adept in testing and refining and translating, here in Australia, because that's what pushes us forward.

Third and finally, our research institutions should aim to be among the world's trusted information sources. Let me ask you a question. How many of you would say your memory wasn't as good as it used to be? How many of you would like to boost it?

Excellent – you will all be interested in the Brain Stimulator, one of the most popular examples of an outbreak of transcranial direct current stimulators. The Brain Stimulator comes in the form of a kit. The device. The electrodes. A diagram of your head. And the positioning headband to stop the electrodes from falling off as they deliver zaps of memory-boosting electricity to your temples. Nine-volt battery not included. If you are worried by the metallic taste in your mouth, the tingling or itchiness in your skull, or the occasional flashes of bright light, you can purchase the Saline Solution Applicator Bottle. In other words, you can dab salty water on your head. In the absence of a hypothesis for why it would work, or evidence that it actually does, the Brain Stimulator is a dreadful example of electronic snake-oil.

The good news is that the Brain Stimulator and similar devices seem to be popular only with a small fringe of the do-it-yourself brain-hacking community. But that's not true of the miracle cures for children with autism. The magic pills and potions that promise to cure brain cancer. The myths and stigma attached to conditions like schizophrenia. All of these things are actively harmful to many people.

And they are not just harmful to people in desperate situations; they are harmful to science. They come cloaked as science, they take the focus from science, and they tarnish the good name of science.

We could all lament the reality that the internet is awash with quackery, anecdotes, PR stunts, and media releases. But if it's a problem, it's also an opportunity. I would like to see our institutions build their reputations as the go-to trusted information sources, not just for Australians but for anyone looking for accurate, up-to-date and accessible information.

Take the Queensland Brain Institute. It has done extraordinary work in developing accessible guides and information pages on topics like depression and Alzheimer's. The QBI website is not the usual register of researcher interests and media releases. Instead, it's a go-to resource. It's the place I'll go to for trusted information about brain diseases. Politicians and members of the public will eventually find it and they will remember QBI whenever they think about brain diseases.

Other institutions are also actively investing in their public information platforms. Let's make that a collective focus and a strength.

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So, three things: have a bold ambition, focus on transformational technologies, and be the trusted source. Easy to remember, with or without that nine-volt battery.

I began this speech in Ancient Egypt 2000 BC. Let me conclude by pointing to the day when our descendants look back at 2017 and our best tools seem about as primitive as the honey, the cow and the milk in both ears. It won't take 4000 years. But the brain is so complex that the research to get there will keep many thousands of brilliant researchers occupied for decades, probably for centuries.

Neuroscientists in the audience, your careers will not be limited by lack of questions to answer. The possibilities stretch out beyond our imaginations, but the potential is right here, in our brains. Let's tackle the future, head on.

17. Human Ingenuity in High Concentration

November 23 2016 | Speech at the Australian Engineering Conference

The national electricity grid is a feat of engineering and its optimal operation is a complex engineering problem. So as an engineer, it made a kind of sense to wake up one morning as chair of the National Electricity Market Review established after the South Australian power blackouts. But an engineering degree is also massively useful for careers that go well beyond the discipline, with engineers following a process for defining a problem and testing a solution that can serve as a blueprint in any number of fields. This speech notes that about 40% of engineering graduates are employed outside the discipline, which is a good thing, and suggests an efficient way to solve problems: train specialists, let them loose.

Before I begin my speech I want to clear up a small matter that a number of you have raised with me in the course of the year. Why am I the Chief Scientist and not the Chief Scientist slash Chief Engineer slash Chief Entrepreneur?

It's very simple. As an engineer I deeply believe that our core mission is the pursuit of elegance. What's a title with a slash or a comma? Inelegant, writ large! A title should be a signature, not a job description. So if I took the initiative to stretch out my title to include "Chief Engineer" and "Chief Entrepreneur", I would ipso facto be unworthy of the name. As a scientist, I take great pride in my current signature. And as an incurable engineer, I'm satisfied that it works. I am certainly not the first scientist-slash-engineer-slash-entrepreneur to hold this post, or to venture into the public policy realm.

In preparation for this conference, I wrote an article about the first of our kind known to history: the Ancient Egyptian engineer Imhotep, who lived and worked in the third millennium BC. We know his name because he was worshipped as a god for more than 3000 years after his death. And rightly so.

After all, this was the man who decided that the base of a pyramid ought to be square. His great achievement, the Step Pyramid at Saqqara, still stands today – the oldest stone monument on the face of the Earth. Yes, ladies and gentlemen, it was that rare thing: a pyramid scheme that actually paid. He was also a celebrated physician, poet, astronomer, architect and statesman. First after the King of Egypt, Administrator of the Great Palace, and Vase Maker in Chief. Shorthand title, God. Profession, Engineer.

The engineer in the ascendant

Now I'm not here to tell you that we need to be up there on quite that pedestal today. I do want to put it to you that engineers are very much in the ascendant, in public as well as corporate life, far beyond their bread and butter roles. The Secretary General-elect of the United Nations is António Guterres, an engineer. China is run by an engineer. The CEOs of Amazon, Google, Apple and Microsoft are engineers. In fact, of the 10 largest American companies on the US stock exchange as of last week, five are run by engineers, three are run by Bachelors of Science and one is run by a Bachelor of Applied Mathematics.

Some might suggest that the incoming American President runs counter to this theme. But the man himself would disagree! It just so happens that Donald Trump's uncle was a professor of engineering at MIT, celebrated for his contribution to the design of X-ray machines and radar research in the lead-up to the Second World War. And Donald Trump is very proud of this connection. As he put it, "My uncle used to tell me about nuclear before nuclear was nuclear... I mean, it's a great gene pool I've got right there." Whatever we might say about his grasp of the science of genetics, at least the respect for engineering is clear.

And we could say the same of many leaders in all walks of life, across the political spectrum. These days, if they're not trained as engineers, they try to sound like engineers. They want to think like engineers. And they openly compete for engineers.

So I ask myself, why? What explains this surge of interest in engineering? And what is its appeal – not just to investors and politicians, but to shareholders and voters as well? Yes, it must be the role model provided by prominent engineers, thriving in leadership roles, and delivering enormous value by their talent for doing things differently. But more importantly, I think the answer lies in the ethos that those role models embody – that we are always capable of better things.

> ***"Engineers are very much in the ascendant, in public as well as corporate life, far beyond their bread and butter roles"***

We hear constantly that politics has failed, democracy is dead, the Age of Enlightenment is gone. In other words, humans are hopeless. I've seen countless variations on that theme in recent times. But I've also flown on aeroplanes. I've charged my phone. I've checked my email – along with millions of people all doing the same, every minute, every day. Aviation, electricity, ICT – what do these and countless other systems have in common?

They are staggering feats of technical and organisational complexity. But more to the point, they prove that human beings are constantly making things that actually work. And they work not because people are perfect, but because we can engineer around our own flaws. Yes, we can be unpredictable, selfish and short-sighted. I won't deny it. But at core, we are also ingenious. And engineering – from the Latin ingeniare – is human ingenuity in high concentration.

Of course, the better our achievements, the more that is expected of us. When I started using computers in 1975 I expected every piece of software to have bugs. Now, customers expect their apps to work perfectly. My first car overheated often and needed oil every week. Today, most young drivers have never seen the temperature warning light, would not know where to add water and probably don't even know that engines need oil. Aeroplanes rarely crash, skyscrapers twist and turn in improbable shapes, resources don't run out, the efficiency of our appliances improves every year, and the air quality of our cities is better than it's ever been. And all of this is possible because engineering has given us the space to imagine – but just as importantly, the means to actually achieve, and to do so safely, efficiently and reliably.

Of course that combination of a big vision and a pragmatic path speaks to our anxious age – and often far more eloquently than other disciplines can. Take lawyers, for example. They are capable and necessary. But in my experience many lawyers are fearful of risk. Instead of managing it, they make it their mission to see it and squash it at every turn. And their hypervigilance can be stultifying. In principle, perhaps you could eliminate all risk from a system, at infinite cost. But this would not be conquering risk so much as succumbing to the fear of it. Sometimes, there is more security in a confident leap than a tentative step. And often, it takes an engineer to see it.

The engineering ethos in public policy

Of course, seeing it is one thing. Selling it to a group of lawyers, much less your accountant, is another. This is a lesson I learned in business: you have to bring your team and your clients along. And the most effective way to deal with customer complaints is to anticipate them, and fix them in advance.

The same is true in public policy. As technologists, we have to imagine not only the solution but the web of consequences attached. We must travel the path to the future not only with our goal in mind, but with a commitment to think about the unintended consequences. We have a responsibility not only to our customers, but to those other members of society who might be adversely affected by our solution. We have powerful modelling tools at our disposal that can help us see the unintended consequences. If we look.

With these tools in hand we bear greater responsibility for the calibre of our advice, not less. Paradoxically, with these tools in hand, there is more need for human intelligence – not less. The best algorithms in the world today are still no match for the messiness of human affairs. Prediction needs human insight as well as technical literacy, as the US election made abundantly clear. And if it's true of prediction, it's even more true of persuasion. It demands a bilingual approach, speaking human and speaking machine.

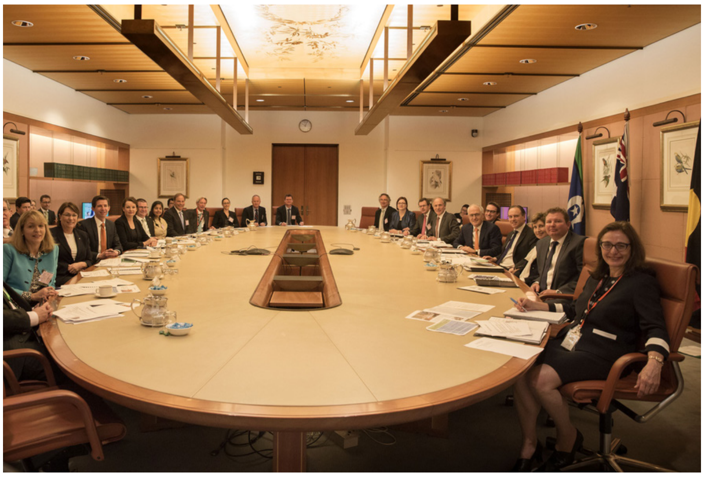
In policy formation, as in business, or in marriage, or in life, you can imagine a better way, but you can never expect to impose it. You can only build confidence that your vision is worthy and the path is sound. That is why I have made it my mission this year to talk not just about what the future might be, but how we can have confidence in our ability to bring it about. And I can report that there's nothing as reassuring to any audience as solid engineering logic.

- First, define the problem
- Second, do the analysis
- Third, build a trial solution
- Fourth, iterate the solution
- And fifth, deliver an outcome that society actually wants

But I don't just explain that logic; I find I constantly apply it, because it works. Ten months ago when I commenced as Australia's Chief Scientist I set out with big ambitions.

Today, I can report that:

- The Commonwealth Science Council has met, with the Prime Minister as Chair, and charged the Australian Council of Learned Academies with a new series of horizon-scanning reports.
- Innovation and Science Australia has been established and armed, as the nation's preeminent future-thinking authority.
- The Fraser-Finkel-Ferris review of R&D tax incentives has gone to the Government, and now to the public.
- The 10-year National Research Infrastructure Roadmap is well in hand.
- And we have made substantial progress on a project that I hope will join ATSE's STELR as a cornerstone of science education.



Commonwealth Science Council, 2016
PHOTO: Copyright unknown

I think of education as a three-legged stool – teachers are one leg, curriculum another, extracurricular activities the third. And you know what happens to a three-legged stool if one leg breaks. So let's look at the state of the three.

Teaching gets a lot of attention. The national curriculum is basically sound. The third leg of the stool, extracurricular activities, needs attention. It's not the lack of programmes; they exist in abundance. Engineers Australia runs many. It's the lack of information and hence access.

Our project, the STAR portal, is going to change that. It is a web platform that will connect the parents, school students and teachers to the growing range of providers, such as dedicated individuals, research agencies, companies and universities. The STAR portal is backed by Microsoft, CBA, BHP, Telstra and the Australian Mathematics and Sciences Institute. And who is managing the project? Who else but Engineers Australia.

In late September, I might have said that the to-do list was more than enough. Then the lights went out in South Australia. And I woke up a few days later as the Chair of the National Electricity Market Review. Fair to say I haven't slept a great deal since.

Saluting the profession

But if I had to distil all of it down to just two words, I would say my priorities are simply the same two words printed in bold type on almost every page of the 2016 State of the Engineering Profession report published by Engineers Australia. It's all about energy and infrastructure. One is the great imperative; the other is the great enabler. And engineers are critical to both.

PHOTO: Copyright unknown

So it's no coincidence that I've spent a lot of quality time in your company, sometimes in power stations, sometimes in research facilities, sometimes in boardrooms. I can say with all sincerity that I have emerged from all my travels with greater appreciation for the breadth and calibre of Australian engineering.

The National Electricity Market, in particular, is a stupendous feat of engineering blended with sophisticated market economics. The more you know about it, the greater your respect for the scale of the achievement – as well as the magnitude of the challenge ahead.

Right across the world, the physical electricity system is undergoing one of its greatest transformations since Nicholas Tesla and Thomas Edison clashed in the war of the currents in the early 1890s. Tesla's alternating-current generation and distribution system prevailed over Edison's DC system, leading to more than a century of central generators supplying the grid. Irrespective of whether the primary power was plunging water, or flaming oil, gas or coal, the spinning generators operated in a synchronous mode that provided not just the electrical energy but also the frequency stability that the grid needs in order to operate securely.

"I think of education as a three-legged stool – teachers are one leg, curriculum another, extracurricular activities the third and you know what happens to a three-legged stool if one leg breaks"

Now, in Australia, we have millions of rooftop micro-generators that operate without movement or flame, distributed throughout the system. We have zero-emission wind farms that are large, central sources like the traditional generators but with new characteristics that we are still learning to optimise. And we have customers who expect to store their own electricity and participate in the market by selling it back to the network operators or their peers.

Our challenge in the face of these rapid and ongoing changes is to design the blueprint for the future electricity system so that it is secure and reliable, but also low cost and a participant in a carbon-constrained world. It must continue to satisfy the stability principles of control engineering, while being consistent with the underpinning logic of market forces as the primary drivers of sound decisions.

Fortunately, in my discussions with governments, systems operators and consumers I have found a genuine enthusiasm for change and a desire to help. On that topic, you'll hear a great deal more in the months ahead.

An agenda for the engineering profession

The upshot for today is that the National Electricity Market will remain a work in progress for engineers, working alongside regulators and economists. It will rely, as long as it lasts, on a healthy pipeline of capable leaders and well-trained graduates.

But we could say the same of every industry, every utility, every hospital, every home. The good life needs great engineers! Many of them will be needed in classic engineering roles, but more and more will be needed in public agencies and corporate boards.

Our challenge today, as the custodians of the profession, is to decide who we recruit, how we train them, and what sort of jobs we encourage them to do. So let me conclude with a few thought-starters on that theme, in the spirit of the incurable engineer. It seems to me that, for all its strengths, engineering like all disciplines has to be constantly on guard against the growing appeal of two great myths.

PHOTO: Copyright unknown

The first great myth is that engineering students have to become engineers – or in other words, that engineering is a tunnel to a predetermined job and not a door to any number of opportunities. This has never been the case – in Ancient Egypt or the modern era. It is certainly not true today.

We have entered an era where more than half of school leavers enter universities. The inevitable consequence is that enrolment in professional degrees is growing faster than job opportunities in the associated professional roles. We produce 15,000 law graduates every year for a legal profession with only 66,000 jobs. Only one in 20 economics graduates becomes a professional economist. Medicine is on the verge of oversupply, and there is plenty of talk of gluts in teaching and accounting.

Engineering is in better balance. Of the existing 400,000 or so workers in the engineering population today, some 40% are employed outside the profession. The fact remains, many engineering graduates will need and want to do what graduates have always done, which is pivot from the conventional path, by using their skills in different ways.

Is that a problem? Not necessarily. It may well be the master plan! My son, Victor, chose aerospace engineering because he wanted to go into management. He never intended to practice as an engineer, but from his discussions with his father he was convinced that the engineering way of thinking would serve him well in business and management.

For my part, I chose engineering because I enjoyed it. No other reason. Actually, of all the reasons to choose an undergraduate degree, doing something you enjoy is probably the best. From electrical engineering I pivoted to neuroscience, manufacturing, publishing, education and public policy. Engineers, of all people, ought to thrive on change. We ought to be capable of inventing the sort of jobs we want to do.

If graduates doubt that capability in themselves, then we have failed. But that brings me to the second great myth, which may well be more dangerous in the long run than the first – that broadening the opportunities for graduates means hollowing out the degree.

By that, I mean replacing discipline content with generic workplace competencies. Or worse still, lowering the bar, at entry or exit. It would be disastrous for the reputation of the profession, and it would do no favours to the graduates themselves.

As a CEO, I want to hire a candidate who has demonstrated the capacity to learn. Mastering one discipline gives you the mental toolkit to tackle the next. I know that graduates from an Australian accredited course have both the intellectual capacity and the inner fortitude to accomplish challenging things.

Now, I would be happier if universities would set students up for success by bringing back advanced mathematics as a prerequisite for any engineering degree. In my idle moments, I wonder if we could introduce an interview process alongside the ATAR. Could we identify those students who come to engineering with raw ambition, as well as a raw score? Perhaps. But irrespective of the way they enter, the graduates who exit should be masters of content, maestros of ideas. Let’s teach them that way.

And let’s hold ourselves to the same standard. If you’re afraid of change, you’re in the wrong room. If you thrive on it – welcome to this conference. Friends, it’s time to engineer Australia.

18. Red Tape or Gift Wrap: Regulation for Exceptional Tertiary Institutions

November 9 2016 | Speech to the inaugural Tertiary Education Quality and Standards Agency (TEQSA) conference

Most people think that standards and regulations stifle innovation. I disagree. As a businessman, I learned that clearly articulated regulations make it easier to design, manufacture and sell your products. It's like sport – if you play by the rules the game flows smoothly. There are, however, two types of regulations. Prescriptive regulations that detail step by step what a university or business must do are a stifling burden. Performance based regulations allow flexibility but ensure quality and fairness. The university sector is not immune from deregulation and the shift to online learning. But in this address to the Tertiary Education Quality and Standards Agency, I highlight the importance of appropriate regulations and urge caution before allowing institutions that are not universities and private providers to award degrees. We must learn from the experience of the vocational sector, where the arrival of myriad new entrants virtually without rules led to a disastrous collapse in quality, and honest students paying for dishonest courses. Regulations must encourage collaboration between higher education institutions, ensure transparency in information about institutions and degrees, and be attuned to the crucial difference between a job-ready graduate and a work-capable one.

When I was asked to speak at this inaugural conference I leapt at the chance. Some people have the curious idea that the topic of regulation is somewhat dry. I take the opposite view. I say that regulation is the Chief Executive Officer's best friend! That's at least as true as the old saying about a man and his dog.

Mind you, there are many dogs you wouldn't want as your best friend. Yappy ones that won't let you get on with your work. Expensive ones that keep the vet bills coming in. Vicious ones that scare away the gardener. And the same is true of regulations. They can slow you down, cost you money and limit your market. Either because they were badly conceived, or simply grew old. But get it right and you have a healthier life and a happier home.

I have had the opportunity to consider what good regulation looks like from several perspectives. First, as a student and researcher. Second, as a developer of medical devices. Third, as a journalist and commentator. Fourth, as an architect of education programs. Fifth, as a policy adviser. Six, as Chair of the National Research Infrastructure Roadmap. Seventh, as one of the three members of the Ferris, Fraser, Finkel Research and Development Tax Incentive review. And now eighth, as the Chair of the National Electricity Market Review. In all of those roles, I have felt the frustrations of regulation done badly – and pursued the returns on regulation done right.

So I say with absolute confidence that TEQSA's role is vital to the future of higher education, just as higher education is vital to the future of Australia. Nick Saunders understands this, as does Anthony McClaran. That's why they have been leading TEQSA to find just the right touch. Where else would I rather be than the opening session of the inaugural TEQSA conference?

And I want to launch this event with perhaps a different message than we usually hear. If you can forgive the pun, I want to repackage red tape, and unwrap the opportunity inside.

The global context – not just the Australian challenge

And I'm going to pick up the thread with a short diversion to Sweden. In June this year a Swedish university was sued by an American student for awarding her a "worthless degree". Wait for it. The student won. The court ruled that her course offered students "no practical value". The compensation was assessed at $US20,000. The course in question was "analytical finance", which somehow taught the student enough to know she had been dudded, but not enough to actually be useful. Clearly, a dangerous combination.

I hasten to add that I am unaware of any similar cases involving Australian universities. But it does raise questions about the purpose and direction of higher education at the heart of our deliberations today.

As a human institution, the university is almost 1000 years old, and for all that time, it has served us well. It has unleashed knowledge, empowered individuals and energised progress. And so it takes much of the credit for the shape of the world as we know it, a world in which change is constant, and knowledge is king. But what is higher education's place in this world that knowledge has created? What are the sector's responsibilities to all the people it serves – from students and staff, to business and the community, to science and society? How do we, as leaders and administrators, make the countless small decisions that add up over time to transformational change? When we talk about regulation, we are really looking for answers to these questions, and asking ourselves what we can reasonably expect.

The winds of change

And reasonable, in this context, could be settled in many ways. Who decides? Is it the sector? Is it the students? Is it their parents? Is it employers? Is it government? Is it the market? Is it some undefined balance of them all? On any given topic, there will be multiple interests in play. And the world won't wait whilst we work through the debate, any more than the tide will wait whilst we work out how to swim.

We all feel the headwinds of change, but let me put them briefly.

1. We are catering to many more students, with a broader spread of interests and abilities.
2. We have a globalising market of providers, giving students far more freedom to shop around.
3. New technologies are changing student expectations, bringing in new players, and opening up a whole new front for competition.
4. There is growing pressure on public budgets, with clear direction from government to seek funding from private and philanthropic sources.
5. All of these changes are playing out in a TripAdvisor world, where everyone has an opinion, most of us have the means to comment, and many of us are calling for better metrics to assess those claims.

Put it all together, and yes, it's complicated. That is the context in which we meet today to determine what best-practice regulation will achieve, in whose interests, and how.

Building on a platform of strength

Let me repeat, it is the global context that counts. In global terms, our universities have answered the call to change extremely well. Let me pay homage here to the leadership of our vice-chancellors who, for more than two decades, have coaxed their massive institutions to embrace disruptive change, rather than succumb to it.

On any measure, our country is a destination of choice for international students. We have maintained our quality brand through a time of unprecedented growth in domestic enrolments. At the same time, our position in the international rankings has steadily improved. High rankings and booming markets are more than just bragging rights, they are beacons that attract those with the ambition to truly excel.

So we ought to be proud of our achievements, and determined to keep up the pace. Our regulatory system should support that ambition.

The ingredients of innovation

And let me emphasise, accepting change does not mean framing the future negatively! On the contrary, it simply shifts the competitive advantage in favour of countries such as Australia which are adept at riding the trends. We can call it ingenuity, innovation, nimbleness, agility, or any number of words. The essence of the idea is the same, and so are the four ingredients that any organisation needs to be competitive. And I have listed these four ingredients in many forums in recent months.

The first is leadership. It is true for a school, a university, a company or a country. The leader sets the vision, delivers the inspiration and ensures delivery against the objectives.

Second, human capital. Every organisation needs a skilled workforce to make sure the leader looks good! And, more importantly, to make things happen creatively and efficiently.

Third, venture capital. Actually, it doesn't matter where the money comes from, as long as it appears. It could be venture capital, bank borrowings or government grants.

And, last but not least, effective regulation. With effective regulation, the organisation knows the limits and can get on with business. With effective regulation, risk is taken out of the business because it is playing by the rules. With effective regulation, your competitors cannot game the system to reap an unfair advantage. As I said, effective regulations are a CEO's best friend.

And here is the most important thing to keep in mind about regulations. From the public policy perspective, the purpose of regulation is twofold – first, to ensure consumers benefit; second, to facilitate commerce. Let me repeat that. First, to ensure consumers benefit. Second, to facilitate commerce. In the first instance, we advance the legitimate interests of the public; in the second, we build the economy. Both of those objectives are served by a system that rewards the pursuit of excellence – because quality is, and must remain, our national brand.

This approach applies to all industries, as I am constantly reminded. Take, for example, the Australian trucking industry. I have a colleague, Peter Hart, who is now a national authority on truck safety and fire hazards. He made the point to me that the public doesn't like trucks in general, and big trucks in particular. We do like cheap freight. So there's a balance to be struck.

Twenty years ago, every jurisdiction would strike a different balance. Roads would cross borders, but the rules wouldn't. Now we are reaping the benefits of the push to a national approach. With care, we have liberalised the length, mass and configuration limits to make way for giant B-triple combinations and BAB-quad road trains. And bigger trucks means fewer trucks and cheaper freight.

PHOTO: TEQSA

Peter describes the approach as carrot and stick. You can have a bigger truck if you accept a higher safety threshold. The higher safety thresholds are achieved by requiring that new trucks meet performance-based standards, as opposed to prescriptive rules. In trucking, as in all industries, prescriptive regulations become outdated when technology advances and people find a better way of achieving the same end. The end result has been good for the public and good for commerce, with safer trucks that are more cost effective to operate.

Further, because compliant trailers are not available from international suppliers Australia has maintained an innovative local manufacturing industry worth $2.5 billion per annum. Enlightened legislation – good for the public and good for commerce.

From trucks to textbooks

Now I acknowledge that higher education is a very different game, but the same basic principles of good regulation apply. We want to see institutions competing for new ways to excel, not locked into a specific definition of what excellence entails. TEQSA arguably didn't get the approach right when it was first formed, but in the past few years it has adopted performance-based standards, just as road managers did for trucks.

Operating within performance-based standards, I can envisage any number of new means by which providers might want to offer a quality service, in line with our quality reputation. In the last 10 years we have seen prolific growth in platforms such as Blackboard and Second Life, as well as increasingly sophisticated approaches to their use. We have also seen globally competitive ed-tech startups such as Smart Sparrow, FutureLearn and Canvas make it easy for instructors to develop online material. In Australia we have a fin-tech sector built around our strong and stable banks. We have a mining technology sector built around the big miners. We ought to back Australian ed-tech as well.

That does not mean that face-to-face teaching is doomed, any more than the spread of Nespresso machines has put an end to the local cafe. The human experience has always been the heart of university life and that will not change. In my contrarian moments, I envisage a day when courses will be marketed "guaranteed robot-free". But whether it's a human or a hologram at the front of the class is not the point. What we want, and what I believe TEQSA will provide, is the scope to pursue ideas. And through those ideas we will be able to ensure the provision of choice.

"In my contrarian moments, I envisage a day when courses will be marketed "guaranteed robot-free" but whether it's a human or a hologram at the front of the class is not the point"

By choice, I mean a range of quality options that consumers have the capacity to assess. I do not mean the situation we saw emerge in the Vocational Education and Training (VET) sector, where many new entrants fraudulently took money from the government and left unsuspecting students with heavy debts and no acquired skills. There, the regulator had no teeth. There, the barriers to entry were much too low – an ABN number and a few hours to tick the boxes on a form. And as we know, it played out to an unfortunate conclusion, dragging the quality providers through the mire.

Whilst we work through the consequences and rebuild trust, we do have to think very carefully before encouraging the drift of degree awards from universities to non-university institutions and private providers. At the very least, we want to insist that the non-university providers be subject to extremely tough standards, with a high burden of proof, rigorously evaluated. No more than we ask of our universities.

And we should all reflect on the difference that good regulation can make. Like a good student, we should learn from others. If trucks were not a sufficient example, look at cars. Public safety has benefitted hugely from regulations in the car industry. Annual deaths per billion miles travelled have fallen nearly tenfold in the past 40 years in Australia. And commerce has been facilitated by the ever tightening safety regulations that push carmakers to respond with ever more clever designs that consumers – especially parents – want to buy. By analogy, we all have a stake in TEQSA's lasting success.

So by all means, let's have a robust debate about the details of the regulatory arrangements. But let's remember, the goal is good regulation, which is not necessarily less regulation – there are many rules we should be very grateful that we have to obey.

The basic shape of good regulation

So with our eyes ever open to opportunity, let me frame today's debate by setting out the four basic parameters on which we can agree.

One, good regulation will set the bar high, with incentives for constant improvement.

Two, good regulation protects the fair expectations of consumers. The consumers in this case are the student, the taxpayer who helps to cover their costs, and the employers who hire them on the strength of their degrees.

For all three groups, the fair expectation is that students will emerge from their degree work-capable. It is not fair, or helpful, to insist that they be job-ready – precisely engineered for the requirements of a specific role, which may or may not exist in the form we expect, in the numbers we predict, at the time the students graduate. To today's gathering, there is a modicum of rationality in describing the difference between work-capable graduates and job-ready graduates as being like the difference between performance-based regulations and prescriptive regulations.

The third parameter: good regulation insists on truth in advertising. Where data can play a meaningful role in a good decision, we should collect it and harness it. Further, we should make it available to all consumers in a convenient, accessible and consistent form.

And number four, good regulation facilitates collaboration as well as competition. We should be thinking about how universities can work with ed-tech startups, just as the major banks are working with the rising fin-techs. We should be working out how to incorporate meaningful experiences in industry settings into degree programs, without cutting back on rigour or discipline content. And we should also welcome discussions about how universities can combine in different patterns to share resources and build critical mass. The Melbourne biomedical cluster is a standout example, but of course, there are many more. Whatever the configuration, good regulations should reward those collaborations that genuinely lift the quality of the service provided.

So, four ingredients for innovation, and four parameters for good regulation. A recipe for excellence squared – and I hope an arena for a good clean fight today. Work within that square, set the dial to excellence, and we are primed for the race to achievement.
An Australia with the regulatory edge in education. A sector on the high road to success.

19. The Universities of 2030

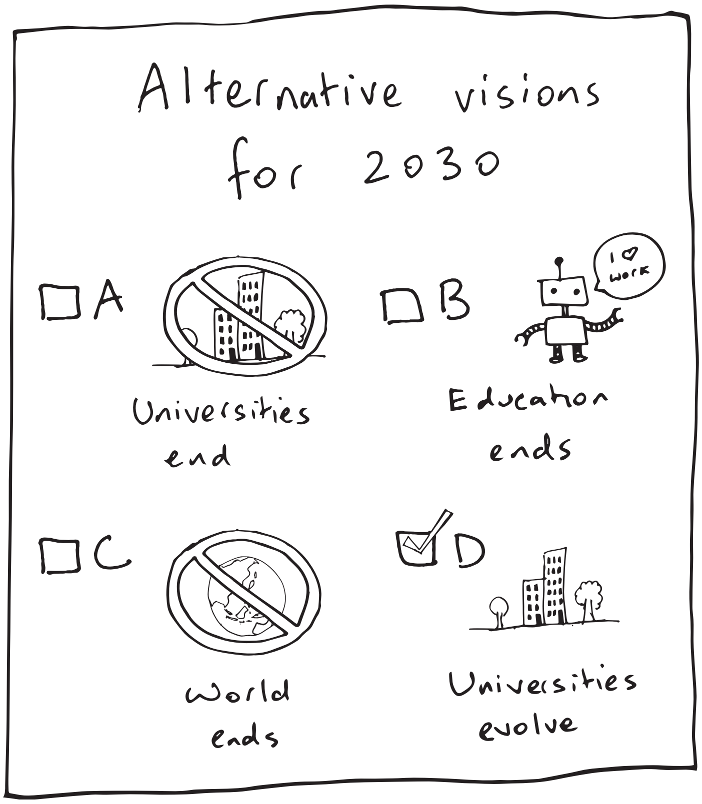
April 29 2016 | Speech at the Office for Learning and Teaching Conference

Predictions about the impact of automation on jobs vary wildly, but however you quantify it, automation is here, it's exploding across workplaces and it's disruptive. Combine this with the fast-growing global middle class, and you have both opportunity and challenge in the university sector. In 2008 I gave a speech in Singapore in which I predicted that most university teaching would be online, provided by just a handful of global universities. My experience during my eight years starting in 2008 as Chancellor of Monash University was the opposite – despite the incorporation of technology into teaching, students wanted to meet their peers and their teachers and spend time on campus. Now, with the forced shift to online learning around the world because of the COVID-19 pandemic, I am not so sure, but I am still willing to predict that human nature will draw students back to campuses. This address at a conference of the Office of Learning and Teaching (OLT) considers the future of digital learning and the need for a new approach that caters for every student, involves every student at a human level, and above all, delivers less a qualification and more a training ground in thinking. It was poignant because in 2016 the OLT was defunded and its investment in initiatives to improve teaching and learning ceased.

There is a very well-known story about higher education. And it goes like this. One thousand years ago, or thereabouts, some people got together. We called them teachers. They attracted some other people. We called them students. The first group delivered lectures to the second group. We called this education. The first group persuaded monarchs and popes to let them engage in this process under a formal mandate. We now had universities.

And pretty much nothing has changed ever since, except the costumes and the scenery. And of course the popes. A thousand years later, the model is clearly under strain. And we are clearly the generation to put it right.

Now here the story splits into a number of alternative visions for 2030. One, universities end, because technologies kill them. Two, education ends, because robots take all the jobs. Three, the world ends, because we destroy it, if the robots don't take the initiative first. And of course, the fourth alternative (and the most likely story ending): universities do what they have always done, which is to evolve to incorporate modern technologies and pedagogies, the question being how quickly and efficiently they get there. Take your pick, and welcome to 2030!



A human future

At this point I need to confess.
I was once a signed-up member of the Doomsday Club. I envisaged teachers replaced by super-intelligent software. Bricks-and-mortar universities replaced by virtual worlds. An oligopoly of online degree providers, like a Presto, Stan and Netflix for education. Princeton, Stanford, Cambridge?

Oh, sure, there would still be a few physical campuses here and there. But think how much prime inner city land we'd free up when most of the campuses are gone! And the few left standing would be ultra-exclusive boutiques for the hopeless romantics still pining for the medieval ways. It was elegant argument based on good engineering logic.

Then I became a chancellor of a university.
Simultaneously, through other channels, I actually had a go at developing some education programs myself. It turns out that humans are a lot messier than engineering logic sometimes implies. So I recant. Or rather, I recalibrate.

I still hold absolutely to the conviction that change is here, it is accelerating and its impact will be profound. But it is human institutions and expectations that will decide what the university becomes. So let me outline the factors I see in play on the path to 2030.

First, the demography. By 2030 the world will have more people – the global population will grow by one billion. More prosperous people – the global middle class will double to 4.9 billion. And a more diverse middle class – the majority will come from China, India and South East Asia. The global market for higher education is booming, and shifting.

Second, the labour market. More than five million Australian jobs – close to 40% of the jobs we do today – are likely to be capable of automation by 2030. Low-skilled workers will be hit fastest and hardest, but professional jobs are far from immune. You can already get financial advice, a medical diagnosis and a prize-winning novel without human involvement. At least you can in Japan. The more expensive the human worker, the greater the incentive to automate the job.

On some predictions I have seen, by 2035 – when our 2030 entrants might be graduating – unemployment could hover somewhere around 45%. In that scenario, 30% of adults hold jobs requiring a high degree of physical dexterity. That leaves 25% in the so-called professional roles – for which the competition would be global and intense. Regardless of the faith we invest in those numbers, it is surely clear that automation means the imperative to get an education will grow. For some, because they want to work.
For some, because they need to retrain. For others, because they simply need a way to occupy their time.

> *"I was once a signed-up member of the Doomsday Club. I envisaged teachers replaced by super-intelligent software – bricks-and-mortar universities replaced by virtual worlds"*

Third, the social expectation. Right up to the present, higher education was the preserve of an elite. It is now the mainstream expectation. In Victoria, we've hit the tipping point:
53% of school leavers went to university in 2015, and 24% to VET, for a total of 77% in tertiary education. So we won't just have more students, we will have much greater spread in the level of preparedness.

Fourth, the politics. 2030 is 14 years and about five election cycles away. We might have a resolution to the political impasse over higher education funding, but I'm not counting on it. I see in Australia the same debate playing out across the world: pressure on public budgets, mass demand for education, universities squashed unhappily in the middle. Although I do note that Norway and Sweden have worked out how to provide high-quality degrees at scale, free of charge. And their economies are doing well.

But that brings me to factor number five: the market, and the technology. Where there is mass demand, there is a mass market. Where there is a mass market, there will be massive investment. Where there is massive investment, there will be massification of the product. But by 2030 it won't be mass delivery of a single product. The real potential lies in the capacity to mass deliver a product custom-fit for every student. That will allow us to get beyond the limitations of the first-generation MOOCs.

In the right context, we know that some MOOCs already work extremely well. I think of the American telecommunications giant AT&T. It employs 280,000 people, or more than the student body at Monash, RMIT, Melbourne and Deakin combined. How does it retrain its workforce? It partners with Georgia Tech and private provider Udacity to develop online courses that 120,000 employees have completed thus far. It is a bold solution, at scale, made possible by a combination of deep teaching expertise and new technology. But MOOCs won't be right for all, as we can tell from the drop-out rates when people aren't required by their employers to complete a course.

What else works? I think of Monash University, where teachers in the Faculty of Pharmacy have set up a virtual island they call Pharmatopia in the fantasy world of Second Life. In Pharmatopia, students can set up fantasy med-tech startups! Run clinical trials! Dispense prescriptions without killing real people! Most importantly, they can interact with their peers and mentors, not just sitting in the same room, but tackling the same problems. The US Marine Corps is heading the same way. It doesn't teach the military history of Ancient Greece by assigning chapters in textbooks. It forces students to think like Athens and Sparta, and replay the battles in online war games.

In 2030, these technologies will seem pedestrian, but their core insight will still be sound. The future of universities is a multiplicity of technologies that can customise and mass-distribute a human experience.

> *"We will reap the success we make, if we have the vision to think at scale and the wherewithal to tackle it together"*

And so we come to number six, the Australian context. All of these trends suggest to me that we have a fantastic opportunity, not an existential threat. A growth market in our part of the world. Strong support for higher education in the Australian community. Pioneers in digital technologies, and in particular, digital education. And of course, the benefit of a pre-existing reputation. All of our ambitions for 2030 rest on that foundation. It is vital that we both use it and protect it.

I am aware that this might be the last address a Chief Scientist has the opportunity to deliver at an Office for Learning and Teaching forum. So let me just say this: whatever the future of the OLT, the mission of protecting our reputation must endure. In its current and previous incarnations, the OLT took the best of the lessons learned across the sector and shared them to the benefit of all. It championed the goal of great teaching and reminded us that we cannot rely on research excellence alone. As a sector, we cannot walk away from that responsibility.

To 2030

So let me finish where I started, in 2030. In an Australia where the universities have continued to share their learning and teaching methods. In an Australia that delivers fit-for-purpose education to the huge number of school-leavers choosing a university pathway. In an Australia that honours a 1000-year history by making the centuries ahead even better. Friends, we will reap the success we make, if we have the vision to think at scale and the wherewithal to tackle it together. Let's make it grand.

CHAPTER 04

Women in STEM

"Changing the system for the benefit of those that follow"

Chapter 4 | Women in STEM

Introduction

I grew up thinking that the only purpose of the Australian Census was so that we would know how many Australians there are. But now I know it is a treasure trove of information.

The Office of the Chief Scientist has released two reports on the STEM Workforce – the first in 2016 based on 2011 Census data, and the second in 2020 using 2016 Census data. There was progress for women in the five-year period, but it was incremental. The 2020 report showed that of people with vocational STEM qualifications in the workforce, just 8% were women. Women made up 7% of managers and 3% of executives. Among people with university STEM qualifications, women made up 28% of the STEM workforce, 22% of managers and 13% of executives. STEM-qualified women also had lower incomes than men. For full-time workers with VET qualifications, just 9% of women earned $104,000 or more, compared with 20% of men. For full-time workers with university qualifications, 26% of women earned $104,000 or above, compared with 44% of men. In better news, by the 2016 Census, 49% of science-qualified university graduates in the labour force were women. We have come a long way since women were forced to resign when they married, but there is still a long way to go.

These speeches call for stronger measures to ensure that equal opportunity for women and equal pay for equal work stay top of mind.

20. Equity: A Business Imperative

October 11 2017 | Final Remarks at a Male of Champions of Change STEM Summit

> Progress is patchy. In the worlds of science and research leadership, the energy industry and the engineering profession, I have seen excellent examples of organisations that appoint women to the top roles. And I have seen terrible examples of all-male events and panels. Even with the right regulatory protections in place, women face unacceptable barriers to promotion and leadership.
> Male Champions of Change in STEM is an organisation that recognises the business imperative and supports its executive members to produce change.

It's a great pleasure to give the final wrap after an extraordinarily informative summit. I don't know whether it's coincidental, but today is the United Nation's International Day of the Girl. Pretty auspicious.

Before I respond to some of the things presented today, let me start with a pop quiz. Have you heard of the Finkel Review? Good, but that's not the quiz. Of the panel I chaired, experts in science, economics and electricity, what percentage was female? Sixty percent – three out of five.

One of the recommendations now accepted by the Government was to establish the Energy Security Board for stronger governance in the sector. It's also got five people on it, managing energy security, overseeing regulation, keeping the lights on. Question: how many are female? Eighty percent – four out of five – including the person once referred to on talkback radio as That Woman, Audrey Zibelman. Audrey, the superstar Chief Executive of the Australian Energy Market Operator.

But I know I'm unusually lucky to find myself working with panels and organisations that value women, value them particularly in leadership positions, and respect their talents at every level. I'm reminded today of the many, many women I know who perform their roles exceptionally well.

The Vice-Chancellor of Monash University, Margaret Gardner.

The Secretary of the Department of Industry, Innovation and Science, Heather Smith.

The head of the Australian Research Council, Sue Thomas.

The head of the National Health and Medical Research Council, Anne Kelso.

The CEO of the Academy of Technology and Engineering, Margaret Hartley.

PHOTO: Office of the Chief Scientist

The Chief Executive of the Academy of Science, Anna-Maria Arabia.

The CEO of Science and Technology Australia, Kylie Walker.

And of course, the editor in chief of *Cosmos* magazine, Elizabeth Finkel.

On the other hand, I've seen some terrible counter-examples. About three months ago, I was invited to a large corporate dinner for an international engineering company. Cocktails in a beautiful restaurant, one of those long King Arthur tables, 20 places. I sat down, and there were 20 males, myself included. One hundred percent male.

Last week, I went to a function at another engineering company, and I happened to arrive at the national meeting of their middle management. Same thing: 15 people in the room, 100% male.

This week, I was at the *Australian Financial Review* Energy Summit, where I was the meat in the sandwich between Energy Minister Josh Frydenberg and Opposition Leader Bill Shorten. Afterwards, there was a panel of thought-leaders in the industry. One hundred percent male, including the moderator.

One of the panel, Andy Vesey from AGL, broke into the discussion and said words to the effect of, "This is an all-male panel, and I am a Male Champion of Change, and it is fundamentally unacceptable for me to be in this position. I do it only because of circumstance and the importance of this occasion. Please, never make me do it again." And the audience cheered.

What we are aspiring to is 100% good news stories, no counter-examples, no need for call-outs. We have made progress. Consider the fact that if you were a female scientist in the 1960s, working for the CSIRO, and you got married, you had to quit.

The improvements have been massive but, without doubt, there is a long way to go. The discussion today makes it clear that there are no quick fixes. We heard from our first speaker today, Francesca Maclean, the determination it takes not just to break out of a system, but to change the system for the benefit of others who follow. The walls that exist might not be physical or legislative, but they are barriers nonetheless. It is those invisible barriers, it is those subtle barriers we have to deal with.

> ***"The improvements have been massive but, without doubt, there is a long way to go"***

And from our panel speakers, we heard it loud and clear: this is not just for the benefit of individuals, it is a business imperative. We *all* benefit if we encourage and support women in science. And if you want to lead the charge, you ought to be a good rider.

It is my personal pleasure to be on the Male Champions of Change for STEM, and in particular to see the deep commitment of my colleagues. This group is outcome orientated. It is looking to the future. And for that, I am very proud. My congratulations to all who ran the show today and thanks to all for your shared commitment.

21. It's Time to Notice

June 24 2016 | Speech to Science in Australia Gender Equity (SAGE) Symposium

We can never fix the problem of gender imbalance without first making the time to notice – across education institutions, industry and other sectors of our society and economy. The university sector is a drive of social change, and should be at the front of this issue also, with equal numbers in management, teaching and research, and equal senior salaries. At the Australian Academy of Technology and Engineering, where I was former president, we instituted hard targets. In 2011, we set a target of at least 33% of women among the new fellows each year. With that achieved, the target is now 50% by 2025. This has been done with the merit principal firmly in place. When I was president, half the board members were women. When I was Chancellor of Monash University, half the council members were women. It was deliberate policy in both cases, and in both cases it was a pleasure to lead superbly capable memberships.

A few weeks ago, an article turned up in my email inbox. It was by Tim Dean, the editor of the website The Conversation. And it was about a scandal that blew up after my appointment was announced last October. Of course I don't like to see my name attached to any scandal – so I read Tim's article with great interest.

It turns out that Tim put together a story back in October that included a round-up of comments from senior figures in science. It just so happened that every one of the senior figures he spoke to were men. So he failed the equivalent of the "panel pledge" that Elizabeth Broderick spoke about. That is, a man published an article on men talking about a man.

That last man just happened to be me, but I declare it was not my fault! It was Tim's fault, because he hadn't noticed. And that was precisely Tim's point. If we don't notice, if we don't consciously commit to the goal of eliminating gender imbalance, then we perpetuate it. On the other hand, if we do notice, then ultimately we can work in a society in which we no longer need to notice, because gender imbalance has gone to the dustbin of history, where it belongs.

So we are here today to notice. To reflect on what we have done well. To reiterate that we need to do better. To work out what that means in practical terms. And most importantly, to commit to be held to account for what we achieve.

> ***"If we don't notice, if we don't consciously commit to the goal of eliminating gender imbalance, then we perpetuate it"***

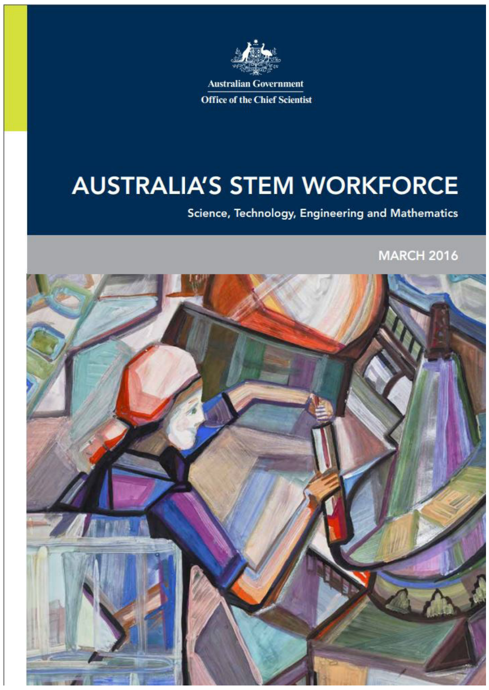
The goal

And this is vital work. I say this personally, and as Chief Scientist. I look to universities not just to reflect our society today, but to model the society we want to be tomorrow. For 10 centuries, universities have been drivers of social change. And if you don't agree with that statement, perhaps you are sitting in the wrong room. Fighting gender imbalance is not just in our interests – it ought to be in our institutional DNA.

So I refuse to give way to the tyranny of low expectations. When I look across the country, I want to see, on average, the same presence in management, the same presence in teaching and research positions, and the same salaries across senior levels. And I want to see in every discipline, a shared understanding that diversity is strength. On my reading of the evidence, we are not there yet.

The path to the status quo

Here are a few facts from the STEM Workforce Report published by my office this year. It draws on the latest available data from a comprehensive nationwide survey – better known as the national Census. The last one was in 2011. At that time, of all university graduates in STEM fields, fewer than one in three were female. One in three male STEM graduates was in the top income bracket, but fewer than one in six women. Women made up more than half the early career researcher population, but fewer than one in five of our senior academics. That's a snapshot in time. To understand it, we need to view it in context. We are seeing progress, if not at the rate we want to see.



Of course, there has been massive improvement since the late 1940s, when the brilliant radio astronomer Ruby Payne Scott had to conceal her marriage to keep her job at the CSIRO, and then had to resign for the crime of pregnancy.

Even in the past decade, there has been measurable progress. We know that the number of graduates overall is increasing. Against this background of growth, in the five years to 2011, the number of female STEM university graduates grew faster than the number of males – a 35% increase for women, compared with 29% for men.

And just this week, our national press gave up its usual preoccupation with failure and catastrophe to celebrate the fact that the first female student has been selected for the Australian Informatics team for the Science and Mathematics Olympiads.

As Chief Scientist, I made a commitment that I would celebrate great Australian achievements in every way I can. Where I can celebrate Australian women in science, I'm very proud to do so. But let me say it clearly: celebrating progress does not mean settling for the status quo.

PHOTO: SAGE

2011 is the baseline. When the 2016 Census data becomes available, we will be able to read the trends. And in the meantime, we will continue to say to women that there are solutions, and not just problems in their path.

Accelerating change

So how do we accelerate change in ways that genuinely make a difference for women? Well, we're scientists and engineers – we ought to know how to set about a hard problem.

- Define it
- Analyse it
- Test it
- Scale up for national delivery

We're also leaders and innovators so we know something about changing human behaviour as well. We need to:

- Commit to a goal – wholeheartedly
- Lead from the top
- Explain what we're doing
- Be prepared to be held to account

Athena Swan takes exactly that approach. It makes incentives not just to clear the bar, but to clear it, raise it, and set the ambition for others in turn. It recognises that the challenge and the solution will not be the same in every university. And so it factors in the space to listen to women and learn from what works – be it targeted grants and fellowships; more allowance for career time-outs; hard recruitment targets and a strong representation of women on selection panels; mentoring programs or other initiatives. This is directed evolution, at national scale. And the Australian Athena SWAN pilot will allow us to take the same approach across the broader program framework.

From my own experience, I know we can change the culture if we try. Look at the Academy of Technology and Engineering (ATSE), a body that represents some of the most stubbornly male-dominated disciplines in our sector. Five years ago, we took action. We set a hard target of a minimum 33% new fellows to be female. We achieved it in every one of the past five years. And let me assure you, as the former President – we did not in any way compromise quality to reach that point. We said we wouldn't, and we didn't have to.

And the Academy is not stopping there – as we see in so many institutions, the more women on board, the more they shape the culture, and the faster we all progress. Whatever we do, we need to drive that process, not simply wait for generational change.

22. A Game Played by Aliens

July 22 2019 | Graeme Clark Oration Women in STEMM Luncheon

In the pre-COVID days when the airline lounges were open and busy, Helen Silver, former Secretary of the Department of Premier and Cabinet in Victoria and now a senior executive with Allianz Australia, introduced me to Gabrielle Trainor at a Melbourne Airport lounge. The timing was perfect because I was thinking about an upcoming speech to the annual Graeme Clark Oration Women in STEMM Luncheon. I knew the issues that I wanted to cover, but I didn't have a story line, and what's the good of a speech without a story? Gabrielle gave me the perfect human interest – football! Women's football. In 2019, the Women in STEMM Luncheon aimed to highlight female entrepreneurs in biomedicine and health: Dr Michelle Perugini at Presagen, Professor Mimi Tang at Prota Therapeutics, Dr Tracey Brown at Anatara Life Sciences, and Annette Hicks at IBM Watson Health. Each of these businesswomen achieved success through initiative, resilience and determination, successes that inspired the audience, just like Gabrielle Trainor's success with women's football.

Today, I'm going to step out of my comfort zone. Instead of science, I'm going to talk about sport, specifically, AFL. That's right: I'm going to talk about AFL, to Victorians, in Melbourne. Now this is not my area of expertise. But a few months ago I had the great fortune to run into Gabrielle Trainor, one of the heroes who's been fighting for decades for women's AFL. Gabrielle even has an AFL Women's league medal named after her in honour of the pioneering work she did to develop women's Australian Rules football in New South Wales.

And what Gabrielle had to say ought to put a rocket up everyone who says we can't make much more progress on women in STEM.

Let's think about women's AFL in the year 2000. If you were a schoolgirl in Victoria, you could not play in an AFL competition once you hit the age of 14. Why not? Because there was no competition open to teenage girls. You had to wait until you were 18 to join the senior women's league. And that league was a community competition, without sponsors, played on the worst sportsgrounds, in your spare time, at your own expense.

On the other hand, your twin brother with the same innate ability would be nurtured every step of the way. And by the time he turned 18, he could easily be on a cereal box and pulling a six-figure salary.

Very few people in the AFL hierarchy seemed to regard this as a problem. In Gabrielle's words: "It was as if I was asking them to support a game played by aliens." The argument went round in circles. We don't want to put money into a competition that people aren't watching. But people won't watch if you don't invest the money. Repeat next year. Nothing changes.

Fast forward to 2019. Half a million Australian women are playing AFL! The number of female club teams has risen from about 1000 in 2016 to more than 2200 today.

We're a long way from equal. Talk to Gabrielle, and you get the impression that she's just getting started. But the long-held belief that women can't play AFL, or don't want to play AFL, has been shattered. As has the belief that women and men won't pay to watch women's sport.

We're continuing to see the same thing in women's soccer. And while the Matildas didn't make it into the finals of the World Cup, the level of support they have received is another powerful testament to the importance of positive role modelling.

> ***"We wonder why it took us so long to see what now seems so obvious. Second-class status for women in sport is not acceptable."***

So now, when a teenage girl has a talent for football in 2019, she's got role models on TV. She's got mentors in her local clubs. She's got teachers and friends who say it's okay for a girl to like football – in fact, it's great for a girl to like football! She's not weird, she's not an alien. She's a star.

You can see that virtuous circle starting to form: the standard of the competition rises, it attracts more women and girls, the standard of the competition rises. And we wonder why it took us so long to see what now seems so obvious. Second-class status for women in sport is not acceptable.

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Now, in many respects, the battle for women in science is much less daunting than the battle that Gabrielle Trainor and her colleagues faced for women in sport. For one thing, we don't force girls to drop out of science at the age of 14, but I do acknowledge it is often when interest appears to wane.

We used to require women to leave science when they got married. Thank goodness, those days are gone. Nor do we tell young women that they're welcome to do science socially, but there's zero prospect of ever being paid – whilst signing off on multi-million dollar salaries for their twin brothers.

PHOTO: Convergence Science Network

Science opportunities are much more even than football was for girls in the year 2000. But no-one would pretend that the battle for equality is won. And the more we look, the more we learn about where in the sciences women and girls end up, and see that there is much more work to be done.

And that will be confirmed in a report that I know is keenly anticipated by people with an interest in this topic. It's the second edition of the STEM Workforce Report, produced by my office. It's an important document, because it's the most comprehensive record of who works in STEM, and who is qualified in STEM, in Australia. The first edition relied on data from the 2011 Census. The second edition brings us up to date with the Census of 2016.

I can't say too much about the findings yet, but I do want to give you a small sneak-preview. The good news is that the female STEM-qualified labour force is growing faster than the male. But of course, we are starting from a baseline where men have formed the majority of the team for the first half. So it's very clear that we still have work to do, and especially when it comes to employment – and particularly, for leadership in business.

And as a Male Champion of Change for STEM, along with other business leaders, I am committed to working to improve on what the data are telling us.

Because what we have found is that in 2016 women made up only:

- 29% of the university-level STEM-qualified labour force
- 22% of university-level STEM-qualified managers, and
- 15% of university-level STEM-qualified business owners

This is not the data that I hoped we would be in a position to report to young women in 2019.

But we're not here today simply because we understand that there's a problem. We're here today because we want to say to young women that this can change.

PHOTO: Office of the Chief Scientist

I ask you to refer back to women's AFL and see the virtuous circle: success drives profile and participation, which drives further success. And the context may be different but it seems to me many of the challenges are the same. We are talking about changing the culture. We are talking about supporting the aspirations of women and girls, and addressing the assumptions of men and boys. We are talking about interrupting an intergenerational cycle. All of these challenges force us, in Gabrielle Trainor's words, to be gutsy.

And who better to lead us in that conversation than the leaders on our panel today? I am very much looking forwarding to hearing, and I really mean hearing, what they have to say, and learning from their experiences. These three women are all interrupters of the intergenerational cycle of which I just spoke, and have valuable stories to share with us about some of the challenges they have faced, and the wins they have had on the science playing field. It will be an illuminating panel discussion.

CHAPTER 05

Energy and Emissions

"Shipping sunshine at scale"

Chapter 5 | Energy and Emissions

Introduction

Despite my car running on petrol and the stove at home using natural gas, for most of my life the only kind of energy I explicitly thought about was electrical energy. In tiny amounts. While still at school, I made a crystal radio that operated off the billionths of a watt harvested from the radio waves transmitted from the local radio station. As a PhD student in Melbourne I studied the electrical activity in brain cells, also at the level of billionths of a watt, too small to create a glow in the most efficient lamp you could ever hope to purchase.

Never did I anticipate when I signed on as Australia's Chief Scientist that by the end of my first year I would be leading a review of Australia's National Electricity Market, where the power levels are billions of billions times higher than the power levels in a crystal radio, sufficient to light up our cities, power our factories, supply our energy hungry computers and cool our homes. That was the start of a journey that has embraced solar and wind electricity, clean hydrogen, and low emissions technologies across the major sectors of the economy: agriculture, transport, the built environment, industry and electricity generation. These are a major part of the drive to a net zero emissions future.

After my term as Australia's Chief Scientist comes to an end in 2020, I have been invited by the Government to remain as the Chair of the Technology Investment Advisory Council that will advise the Minister for Energy and Emissions Reduction, Angus Taylor, and the Morrison Government on the annual updates to the Low Emissions Technology Statement. I am delighted to be able to continue working on the best way to quickly achieve a low emissions future, while contributing to economic prosperity and global benefits.

23. National Electricity Market Reform: A Blueprint for the Future

June 21 2017 | Keynote Address to the National Press Club

Reform to the National Electricity Market has been one of the most complex issues, and unquestionably the most controversial and politically charged issue, of my term as Chief Scientist. I didn't intend it that way. The Independent Review into the Future Security of the National Electricity Market (the Finkel Review), which I chaired, was essentially agnostic about the source of energy and focused rather on outcomes: lower emissions, a reliable and secure electricity network, and the lowest possible prices. The review was sparked by the South Australian power blackout, but was overdue. Australia risked being left behind if it didn't respond to changes in the market that had arrived irrespective of political preferences, including investor preference for wind and solar, consumer take-up of rooftop solar and small-grid technologies, and the boom in battery storage, none of which were compatible with a national electricity grid designed for synchronous generators where energy flows predictably in one direction, from large generators to users.

If you ask a friend what's the most complex machine in the world, their answer will depend on their background. A physicist will tell you it's the enormous hydrogen-fusion reactor under construction in France. A biologist will tell you it's the human brain. As an engineer, I'll tell you that the Australian electricity grid is a contender. I am in awe of the 5000km long network that stretches from the far north of Queensland to the west of South Australia.

The National Electricity Market, fondly known as the NEM, is a stupendous feat of engineering blended with sophisticated market economics and governance. Its formation was a powerful example of cooperative national economic reform. But in its essence, it is one giant physical machine. And as you know, every machine of any type needs preventative maintenance to minimise the risk of breakdown. In September last year, the electricity supply in South Australia blacked out. This was the first time an entire state had gone dark since the NEM was formed in 1998.

In response, COAG Energy Council commissioned our review. But our review was not tasked to analyse that one event. The primary purpose of our review was to develop a national reform blueprint to maintain security and reliability in the NEM. To do so, my fellow panel members – Chloe Munro, Karen Moses, Mary O'Kane and Terry Effeney – and I drew on our collective experience in electricity generation, distribution, retail, governance and commerce.

We conducted an exhaustive consultation process with large industrial users, energy companies, industry groups, consumer groups, academics, public servants and ministers. More than 390 submissions were received. The panel attended more than 120 meetings with stakeholders. Around 450 people attended consultation sessions. Internationally, we visited regulators and operators across Europe and the United States. On our request, the International Energy Agency, headquartered in Paris, prepared a review for us of international best practices. We commissioned independent economic modelling of various scenarios. Finally, we asked the power systems engineers in the Faculty of Engineering at the University of Melbourne to look at how the physical electricity system would perform under our policy scenarios.

Throughout, we identified ways to ensure the optimal operation of our electricity system in Australia. And the deeper we dived, the clearer it became to us that to capture these opportunities the NEM needs to embrace new technologies and practices.

As we engaged with individuals, companies and organisations across the five states and one territory of the NEM, the cries for change were loud. The common chorus we heard was that the NEM needs to evolve much more quickly than it has to date. Business as usual is not an option, they said.

Historically, our electricity system has served us well, but as we described in the Preliminary Report last December, the NEM was designed for a different world. The economics were different. Demand grew every year. And prices were low because most of the coal and hydro generators were established by state governments.

The technologies were different. Until about a decade ago, we had enjoyed 100 years of technological sameness. Electricity generation technologies got better decade by decade, but they were fundamentally the same as their predecessors. Whether their primary energy source was coal, gas, diesel or hydro, they all operated as so-called synchronous generators. Electricity flowed in one direction, from large generators towards end users. The electrical load curve during the 24 hours of the day rose and fell smoothly and predictably. Thus, the coal fleet could slowly ramp its output up and down to match the load during the daily cycle. Those days are irrevocably gone, here and around the world. Consumer demand patterns have changed. Disruptive technology has lived up to its name.

One technological disruption is that ever cheaper wind and large scale solar, even without subsidies, are dominating investor interest. Investors prefer wind and solar because they are now cheaper to build than traditional generation such as hydro and coal. Investors also like wind and solar because they can be rolled out in small steps, say 100 megawatts at a time, then scaled up to meet demand. This minimises the risk that by the time a much larger project is finished the increased demand might not have materialised.

A second technological disruption is the nearly two million rooftop solar generators that householders have installed. The electrical load curve and the generation mix now ramp rapidly up and down during the day to the extent that it becomes difficult for slow-responding baseload generation to cope. The market into which coal generation operates has been forever changed.

A third technological disruption is just beginning, delivered courtesy of stunning improvements in battery capacity and cost. This is a grassroots revolution. It's driven by billions of people wanting their smart phones and laptop computers to last longer between charges. To meet that market pull, global manufacturers have invested massively to improve the performance and lower the price of rechargeable batteries. Repurposing these batteries has enabled manufacturers to configure grid scale batteries. These are now being installed internationally at a level and cost that were unimaginable five years ago. And sitting right alongside, we have the prospect of pumped hydro storage, for which many sites have been identified in Australia, including the Snowy Mountains.

A fourth technological disruption results from the fast evolving digital technologies that dominate our lives. Uber, TripAdvisor and Netflix have disrupted the way we commute, travel and seek entertainment. So, too, digital technologies are poised to enhance our electricity system, allowing it to flexibly accommodate millions of distributed rooftop solar generators, two-way current flows and the connection of microgrids.

The final disruption is that homeowners are becoming market participants. Empowered by friendly software, they are keeping tabs on their own power generation, storage, demand management and electric heat-pump heating. Further, there is the imminent possibility of a shift to electric vehicles.

For the past eight months, I have observed our electricity supply struggling to cope with these disruptive changes. But I don't want to exaggerate. The system is not broken. It is, however, at a critical turning point. We must improve on what we have, to prepare for the growing wave of disruptive changes sweeping electricity markets here and around the world. Globally, policy makers and market bodies understand that the key driver of that change – technology – cannot be reversed.

When we met our counterparts overseas, the thing that made the biggest impact on me was the long term policy certainty in other countries, which enables them to efficiently plan for the energy transition. It is clear they are ahead of us. For example:

- Ireland has a multi-year program, Delivering a Secure, Sustainable Electricity System, to actively integrate renewables into the power system;
- The United States has the Quadrennial Energy Review, to enable the modernisation and transformation of the electricity system; and
- New York has the Reforming the Energy Vision strategy, which establishes targets for emissions reductions, renewable generation and energy efficiency in buildings.

These examples illustrate the need for us to adopt a more proactive approach in Australia. The design and governance of our electricity market will need to be resilient to match the constantly evolving market. Resilience is achieved by actively integrating new technologies to ensure needs are met. For example, when it comes to new-generation technologies we can't afford to have them connect to the grid without giving due consideration to their impact on the whole of the system. If we don't actively manage these issues, we'll end up swimming outside the flags.

Since its creation in 1998, the NEM has a strong history of security and reliability. Between 2001 and 2015, the reliability target of 99.998% was met at all times bar one occasion in Victoria and one in South Australia. But since then, there have been warning signs emerging in the technical data. For example, in 2016, the NEM spent more time outside the expected operating frequency band than normal. And in 2015 and again in 2016 the level of system inertia in South Australia was lower than in the previous five years.

Everywhere we went in Australia, we heard first-hand the pain being caused by rising power prices. We heard from the irrigators in rural communities who need electricity to pump water, from copper miners, from meatworks, from welfare groups representing vulnerable consumers – we heard the message loud and clear.

In the short term, the biggest cause of high electricity prices is the cost of gas, which is increasingly setting the prices in the wholesale electricity market. In this regard, I note that the Australian Government made an important announcement yesterday about measures to increase domestic gas supply that will ultimately lead to lower gas and electricity prices. Our review shares the concern about gas supply, and we make recommendations related to landholder compensation, data transparency for exploration and fuel contracts, case-by-case assessments, and last-resort intervention rights for the electricity market operator.

Other factors that contribute to high prices include substantial transmission and distribution charges. The Government announced yesterday it will address these through strengthening the hand of the Australian Energy Regulator and limiting the ease of appeal. These measures are consistent with our review recommendations. In respect to retail charges, performance and transparency are being considered by the Commonwealth Government, COAG Energy Council and the ACCC. Our review endorses that work.

> ***“Reliability, security, lowest cost and reduced atmospheric emissions are the critically important outcomes”***

But for the longer term, it became clear to us that a more fundamental, underlying reason for rising prices in the wholesale market, especially in the price of forward contracts, is investor uncertainty. That uncertainty revolves around current and future emissions reduction policies. In the long term, resolving this uncertainty will put downward pressure on prices by bringing new generation online. This was the overwhelming position put forward by stakeholders during the review.

PHOTO: Copyright unknown

We have thus recommended an orderly transition package that consists of, first, an agreed emissions reduction trajectory, second, the Clean Energy Target to incentivise investment in generation, and third, a minimum of three years' notice of closure to be provided by existing large generators. This last provision, that is, the three-year notice of closure, will provide time for local, state and federal governments to assist communities affected by job losses and reduced economic activity. Importantly, it will also send signals to investors that there is an upcoming electricity generation gap to be filled. This orderly transition cannot be rushed.

I'd like to reflect for a moment on the difference between outcomes, as opposed to the details of where we obtain our electrical energy. The review takes the position that reliability, security, lowest cost and reduced atmospheric emissions are the critically important outcomes. The generation mix is an input. The exact mix of coal, gas, solar, wind and hydro is not important as long as the outcomes are met. To minimise future price increases we will need a diverse energy mix, including fossil fuels.

Our modelled emissions reduction pathway is not a dash for 2030. Instead, it is a continuous trajectory in the electricity sector that reduces steadily towards zero in the second half of the century, consistent with the Paris commitments for the whole of the economy. Along the way, it delivers a 28% reduction in emissions by 2030, also consistent with the Paris Agreement.

Our modelling shows that under the Clean Energy Target there will be 42% renewable energy generation in 2030. The greatest proportion of that will be large scale solar and wind, at 24%, up from 17% in a business-as-usual scenario. In addition, 8% comes from hydro, 9% from rooftop solar and 1% from biomass.

This renewable energy will operate alongside existing coal generators. These coal generators will supply 53% of our electrical energy in 2030. This is 4% less than under business as usual. In 2050, our modelling shows coal will persist at a higher level than under business as usual. The reason is that with policy certainty, the owners invest in major refurbishments, thereby preserving the existing coal generation to achieve emissions reductions at lowest cost.

Because the Clean Energy Target is technology neutral, if the price of gas comes down in future to lower than what is currently estimated, then gas will contribute to a greater extent than we have modelled.

Consistent with the technology-neutral approach to achieving the outcomes, we did not recommend any prohibitions on technology. As an example, if a coal plant were to be built with carbon capture and storage it would benefit under the Clean Energy Target at nearly the same rate as a wind or solar farm.

The key purpose of the modelling is to provide a basis for comparison between different policy scenarios. As is the case with all modelling exercises, the modelling undertaken for this review depends on the assumptions. We have been very clear about our assumptions.

For example, we consulted extensively to determine the financing costs associated with project risk for large projects, and the financing costs associated with uncertainty risk in the absence of an emissions reduction policy.

We were conservative in our estimates of wind and large scale solar generator prices. Indeed, in recent months the prices for wind generation have already come in lower than what we modelled.

Most important, our modelling shows that the price to residential consumers in the long term will be lower by about 10% compared with business as usual, and for industrial consumers will be lower by more than 15% compared with business as usual.

“Our blueprint seeks to co-optimise four outcomes in the NEM: future reliability, increased security, lowest possible prices for consumers, and lower emissions”

I took into this review what I learned during my working career not only as a scientist and as a businessman, but as an engineer. That is, engineering is the art of optimisation. You can’t build a bridge based on pursuit of perfection. That would be too expensive. You can’t build a bridge based on compromise. That would result in failure. Instead, what you can and must do is build a bridge by optimising all of the variables. Our blueprint seeks to co-optimise four outcomes in the NEM: future reliability, increased security, lowest possible prices for consumers, and lower emissions. Not easy, but my colleagues on the panel and I have no doubt that the combination of new technology with a strategic approach can do it.

To optimise these four outcomes there will be three enabling pillars. First, the orderly transition that I described earlier, to bring into the market new generation and reliability. Supporting this will be an obligation for new generators to be able to dispatch electricity to meet the extreme demand that occurs during Australia’s hot summer afternoons.

The specifics of the requirement will be calculated for each state, looking at present and future needs, while avoiding heavy capital expenditures that would drive up end user prices. As an example, in a state like Queensland, the initial obligation on a 100 megawatt wind farm might be a requirement to provide power, even when the wind is not blowing, at the 10 megawatt level for four hours. The additional capital expenditure would be 10% or less, meaning that the new wind farm would still be cheaper than a wind farm of the same capacity built just a year ago. There are many means by which this capability to produce power when needed could be provided. It could come from on-site batteries or liquid-fuel generators, or it could come from a contract with new sources such as a pumped hydro facility or an off-site gas generator.

The second enabling pillar will be more system planning to ensure the ongoing security in each region of our electricity system.

And the third will be stronger governance through a new Energy Security Board. The Energy Security Board will be key to efficiently delivering the recommendations of the blueprint. Further, it will help to coordinate market development, and it will provide an annual report to COAG Energy Council describing the performance, opportunities and risks in the electricity market.

Above all, our blueprint is a plan to preserve the security and reliability of our electricity system in the face of certain change. It is a plan to do both at minimum cost. Minimum cost, but not the cheap electricity of the past. I wish it were possible. More realistically, our blueprint is about achieving the lowest prices for commercial and residential consumers into the future.

To do this, consumers will also need to be part of the solution. They are at the heart of the energy transition and need to be the centre of governments' plans for the NEM. For example, an important part of the panel's blueprint is to reward consumers for contributing to reliability and security. Incentivising consumers to modify their demand will help to create a more secure, reliable and affordable NEM.

If we don't act now, Australia risks being left behind. Our future will be less secure, more unreliable and potentially very costly. Although we use the term in our modelling in a very specific way, there is actually no such thing as business as usual because the system is dynamically evolving. The past is gone. That's why we subtitled our report a blueprint for the future. To preserve a stable system at lowest cost we need to embrace that future.

Embrace. Not race. Move too slowly and we will miss out on what the future offers. Move too quickly and we put at risk the stability and affordability of our electricity system. Industry and consumers recognise this need for balance and have expressed their support for the Review's recommendations.

In that spirit, I warmly welcome the announcement yesterday by the Australian Government that 49 of the 50 recommendations made in our review will be supported by the Commonwealth at the next COAG Energy Council meeting. I am also pleased to note that the Government will continue to consider its response to the Clean Energy Target and will undertake further analysis.

> ***"Embrace. Not race. Move too slowly and we will miss out on what the future offers. Move too quickly and we put at risk the stability and affordability of our electricity system."***

To conclude, let me pay homage to the insights in the historical novel *The Leopard*, by Giuseppe di Lampedusa. I read this book when it was the prescribed text in my younger son's Year 12 English class, and its central message stuck with me ever since. Thank you, Alex.

The novel opens in 1860 Sicily. Lampedusa's protagonist is the Prince of Salina. He is the head of a regal family that enjoys feudal authority, until Giuseppe Garibaldi lands on the island to violently kickstart the unification movement. The prince's singular goal in life is to preserve his family's power. It's not working. His shrewd nephew sees the need to change with the times, and points out to his uncle that "everything must change so that everything can stay the same".

So, too, if we want to preserve the NEM as a stable and affordable electricity system, we have to proactively respond to inevitable change. A more pragmatic statement of the same principle comes from Jack Welch, the former CEO of GE – the only company to have survived in the Dow Jones Index since the index was formed 110 years ago. Jack Welch crystalised this principle when he said: “If the rate of change on the outside exceeds the rate of change on the inside, the end is near.” The lesson is that the National Electricity Market must change on the inside in order to remain effective.

As I said in the preface to the review, we will know that we have been successful if, in three years from now, electricity is no longer a topic of discussion in the general community.

24. Power and Progress

August 29 2017 | Annual John Monash Oration for the General Sir John Monash Foundation

This speech, delivered to the Sir John Monash Foundation in the weeks after the Finkel Review was released in June 2017, captured some remarkable coincidences between my recent story and that of Sir John Monash. But let the record show that I am not for a moment attempting to close the extraordinary gap between his remarkable level of achievement and my own. First coincidence: I had just finished eight years as Chancellor of Monash University, named in his honour. Second coincidence: I was asked to Chair the review by the then Minister for Environment and Energy, Josh Frydenberg, after he saw me and thought of me at the launch of a new science centre at Scotch College, Sir John Monash's school. Third coincidence: the last great commission of Sir John Monash was the creation of the electricity network of Victoria. Mine was a smaller task by far, but nevertheless we both worked on aspects of gigantic electricity networks. The review was a response to the South Australian power blackouts of the summer of 2016. It pointed to the ageing coal fleet, Australia's 2030 emissions target, the significant uncertainty for investors, and challenges to the network from changes to generation. It set out a plan for increased security and reliability, rewarding consumers for reducing demand, and a clean energy target. It recommended the creation of the Energy Security Board to integrate market design and analysis. And it recommended the development of an Integrated System Plan that today is resulting in the planning of long distance interconnectors that provide end to end system benefits rather than local benefits, and open up solar and wind based renewable energy zones.

General Sir John Monash was one of those remarkable people who blaze through life collecting careers. By my count, he had at least 24. He thrived in peace and war, in business and government, through the Depression and in times of prosperity, in public and private life. And we honour him to this day, on the $100 note. If we added up all the $100 notes in circulation, we would put his value at approximately $30 billion – about the same as the brand of Harry Potter. But, of course, he's bigger than Potter; he's priceless.

* * *

Now without doubt, anyone would be flattered by the opportunity to deliver the John Monash Foundation Oration. But for me, it's personal. It's eight years I served as Chancellor of Monash University, and the 52,512 new graduate hands I shook in that time. It's the hours of my life I spent on the daily drive to and from Monash University, on – wait for it – the Monash Freeway. It's the John Monash Scholars I've come to know, some of them in the audience tonight, and all of them incredible people. And most of all, it's a night that's seared in my brain, that could almost convince me to believe in fate. Almost.

Thursday, October 6, 2016. I'm driving home from speaking at the launch of a new science centre at Scotch College. Scotch College: John Monash's beloved school. It's approaching 11 pm, and I take a call from the Federal Minister for Energy. "Alan, would you accept a commission to take on electricity?" Electricity – the last great commission of John Monash's life. As the inaugural Chair of the Victorian State Electricity Commission, from 1920 until his death in 1931, General Monash was truly a father of the electricity grid. Our very own General Electric, as well as my personal hero.

I clocked in for my first full day at work on our National Electricity Market review on October 8, the very day we marked the 85th anniversary of Sir John Monash's death. And ringing in my ears to this day are the words that he delivered in a speech from 1924, one of the many salvos he would fire in this last great phase of his life. Let me read them to you.

"Electric energy has become the servitor of humanity. Its utility is destined to expand until it dominates future civilisation.

"Even our homes have been invaded, and the conditions of domestic life have been wholly transformed.

"The world is becoming, by a process of peaceful penetration, steadily, but none the less surely, electrified."

The title of his speech was "Power and Progress: The Era of Electricity." We could have borrowed it verbatim for the Review of the National Electricity Market – the so-called Finkel Review – that we published in June this year.

* * *

No, I don't believe that even General Sir John Monash could have orchestrated events to create the perfect lead-in to a John Monash Oration. But I do know what it's like to be haunted by the very thought of his disapproval. He just had that effect.

Well into the 1960s, Prime Minister Robert Menzies would tell the story of a long distant day, in the midst of the Great Depression, when the Victorian Government dared to refuse Sir John Monash a request for £1 million – about $75 million in today's money. Menzies was a junior minister in Victoria at the time. When Monash heard the news, he invited himself to a meeting with the Premier and Cabinet, which the Premier found he could not refuse.

As Monash entered the room, all present rose to their feet. “Mr Premier, I gather that the Cabinet has rejected my proposal.” The Cabinet, collectively, shuffled its feet. “Well, that can only be because they’ve utterly failed to understand it. I will now explain.” Half an hour later, with the Cabinet reduced to a withering heap of abject misery and desperate repentance, Monash produced the necessary legal contract. It was signed, and Monash departed with his £1 million.

More than three decades on, Sir Robert Menzies lived with the trauma of that occasion. But I think he saw it as character building. And sometimes I think to myself that it wouldn’t be such a bad thing if we all lived with that image of Sir John Monash, waiting just outside the door, ready to walk in and bludgeon us into submission by his brilliance.

How would we tackle the great challenges of our time if we could live up to the Monash expectation? In particular, how would we tackle the challenge that I was gifted on the night of October 6, the challenge that Sir John Monash called Power and Progress, and that we have inherited as the great Electric Trilemma? Electricity! Make it cleaner. Make it cheaper. Make it constant. And in the spirit of Monash, make it happen. I am convinced that we can, and if our recommendations are adopted, we will.

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But let me step back from the Electricity Review for a moment to give you a sense of our place in history. In 1924, Monash drew a line in time and called everything to the right of it the Electric Age. In hindsight, we might describe it as the Electric Age 1.0. It was built on the assumption that there would be one statewide grid and one government-owned operator. The electrons would come from a few big generators. Those generators would burn Victorian coal. The electricity would then be used for lighting, cooking, industrial processes like smelting, and to power the motors of our factories and public transport. Centralised, controlled, predictable: Electricity 1.0.

The next age began with computers. Why? Because computers completely overturned the expectations. Before computers, a blackout that lasted a day would be inconvenient. After computers, a blackout that lasted a millisecond could be catastrophic. And computers did something else as well – they souped up science, technology and innovation to a frantic pace.

With the aid of our thinking machines, we began to envisage a world where electrons could come from a solar panel on your roof. Where two million solar panels, on rooftops all across Australia, could feed into the grid, along with wind farms and solar farms and gas-fired generators and batteries. Where the one grid could be broken up into microgrids, allowing households to trade their electrons, peer to peer. Where you could manage all these things from the opposite side of the world, via an app on your phone. Where everyone on the planet, all seven and a half billion of us, would demand the incredible electric life we take for granted. Where cyber-criminals and solar storms and a speck of dust colliding with a satellite in space could turn our orderly existence on its head. Throw climate change into the equation, and you have disruption. Rampant disruption. Electricity 2.0.

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And so we come to our place in the story, another bright line in time. And we cast our minds forward to what might come. In the past, I've called it the Electric Planet, but we could think of it today as Electricity 3.0. Please note that it falls in the chapter of the Finkel Review we called "Beyond the Blueprint". It takes us several decades into the future. Electricity 3.0 looks like this:

- We convert all electricity generation to zero-emission sources.
- We back up those sources with storage technologies we've scarcely begun to imagine.
- But it's not enough. We need to double it. Triple it.
- We ramp up that cheap, reliable and clean electricity production.
- Then we run the world electric – electricity instead of petrol in cars, electricity instead of gas heating in homes.

I repeat, beyond the blueprint, but well worth keeping in mind.

So there we are, at our particular moment on the timeline. From the past, the brilliant legacy of Sir John Monash. To the future, Electric Planet, Electricity 3.0. Right here, right now – the great challenge of our time.

> ***"Aspiration. Encouragement. Education. We need all of them to get things done."***

How would I urge you, the present and future leaders of our society, to proceed? Let me boil my answer down to three words: aspiration, encouragement, education. Aspiration. Encouragement. Education. We need all of them to get things done.

Number one, aspiration. Aspiration is not simply imagination. It is imagination plus action. It is striving for the dreams in your mind, in the rock solid belief that there is always a better way, and if you want it, you can claim it. That ethos is the essence of good engineering.

John Monash expressed it as the difference between executing an instruction, and reframing the expectation. He thought that the country was bogged down, lacking in vision and incapable of imagining anything better than just doing more of the same. He said so, all the time. And he treated the country's engineers as the equivalent of the jump leads on the nation's soul, connected to the battery of his brain – his way of firing up the impulse for change. Evolve the vision, mature it, and share it, he said to his fellow engineers; help people to work together for a future they might actually want. Not just different, but better!

I have now spent the past 10 months of my life travelling the country, listening to businesses and communities, and talking to public servants and politicians. My colleagues and I had one goal in mind – to frame the way forward for Electricity 2.0.

It was clear to us that there is a passionate desire for change. And those who are the most passionate – those who seek out the evidence, reach for solutions, put skin in the game – are those who are driven by the vision of a better future. Not those living in the mirage of a golden past. Not those warning of a global apocalypse. Those with aspiration. Those who say our electric future can be great, should be great and will be great.

Number two, encouragement. The next time you're cruising down a highway in California, or zipping around Norway, you'll see something new and striking on the side of the road. Stations where you can charge an electric car. And the charging units at these stations are beautiful. Streamlined, elegant and gleaming. When you plug in, you feel a surge of pure future.

Where did they come from? Would you believe me if I told you that they came from Queensland? That the very first time I saw this charger, it was just an ugly sheet metal box with protruding wires, like a partly disassembled Dalek from the props department of Doctor Who. That the proud owners and builders were three young men, who initially set out to develop an electric vehicle motor controller, with no idea that they would one day be building electric highways all over the world. It's true. And it's a reminder that dreams do scale – with encouragement.

Back then, I was involved with an electric vehicle company called Better Place. I led our company in a project to support those three young men, and their company, Tritium, to develop their prototype fast charger. Through our own vision of a transformational new market, we encouraged Tritium to pursue a novel opportunity. They also received encouragement from the University of Queensland, where the founders met as students in the University's Solar Car Racing Team. Subsequently, they were backed by public investment; and just as importantly, encouraged to demonstrate their technology in pilot projects here in Australia. Then they were able to tap into some of the best business mentors, investors and partners across the world, catching the surging momentum towards electric cars.

From left: Ms. Lara Olsen (John Monash Scholar), Dr Alan Finkel and Ms. Kelly Bayer Rosmarin (Group Executive for Institutional Banking & Markets, Commonwealth Bank of Australia) during the Q & A of the 2017 John Monash Oration
PHOTO: John Monash Foundation

A fortnight ago I picked up a copy of *The Economist* magazine. On the front cover, a picture of a clapped-out petrol engine, oozing oil and covered in rust. Above it, in giant letters, the word "Roadkill". On the inside, the lead article, with the title, "The death of the internal combustion engine". Incredible to read it in *The Economist*, one of the most significant journals of our time. Incredible to even think it. But that kind of great change is simply the sum total of many courageous decisions, not just by students and inventors, but by investors and governments and consumers and regulators. Courage.

General Sir John Monash knew a great deal about the art of encouragement. He inspired men in battle just like he persuaded governments to give him £1 million at home. Relentless preparation, mastery of the detail and willingness to take absolute responsibility for the outcome. That is how he encouraged others not to take a leap of faith, but instead, to take a calculated risk. Venture capital is important, but courage capital, well-invested, is gold.

And finally, to number three, education. Part of the Monash legend is the story of the day in 1930 when he was invited by some disgruntled compatriots to lead a military coup. Monash replied, by letter: "Depend upon it, the only hope for Australia is the ballot box and an educated electorate." He was right.

But education is not merely the prerequisite for a measured, respectful, intelligent public debate – and yes, I do believe that such a debate is possible. Education is the way we arm ourselves for life.

> ***"Education is the way we arm ourselves for life"***

And Monash, who sat for 94 examinations in 17 years of tertiary education, knew its power, far more deeply than most. One of my duties as Chancellor of Monash University was to do the honours at graduations and listen attentively to the Vice-Chancellor's speech. At least 20 times per year. The same John Monash quote would appear every time. And, in fairness to the Vice-Chancellor, it is worth repeating: "Adopt as your fundamental creed that you will equip yourself for life, not solely for your own benefit but for the benefit of the whole community."

In this quote, General Sir John Monash goes beyond today's mantra on what's wrong with education in Australia. The critics chant that we must train our students for the modern world, equip them with "21st century skills". Of course we must. Sir John Monash knew it at the dawn of the 20th century, which is what he meant by students equipping themselves for the benefit of the whole community. But his starting premise was that students had to equip themselves for their lifelong careers, with foundational skills and knowledge.

For them to do so, educators must set the bar of aspirations high. They should raise the bar for every student, in English, in science and in maths. That itself is not enough. Our education system is then obliged, as its most important priority, to do its utmost to help our students to clear the high bar. It's a good model. Let's call it the "high bar and coach" model of education. For proof, look at the John Monash Scholars here tonight. Every single John Monash Scholar is a product of high aspirations and great coaching.

Let me leave you tonight with that final image: General Sir John Monash at the door. Your door. General Sir John Monash who insists it can be done. And General Sir John Monash who says that you're the person to do it. Let's live up to his expectations.

25. International Energy Agency

February 11 2019 | Opening panellist remarks for the International Energy Agency Workshop on Hydrogen

The idea of using hydrogen to power our ships and heat our homes has been kicked around for a couple of hundred years by scientists and science fiction writers alike, but has never gotten off the ground. Till now. This time it's different for three reasons: the international determination to eliminate greenhouse gas emissions, the plummeting production costs and the plummeting utilisation costs. Hydrogen, either direct or converted to a derivative such as ammonia, is unquestionably the exportable energy resource of the future, but there are hurdles to overcome – and no time to lose if Australia is going to be at the forefront of an industry the Hydrogen Council predicts will be worth more than US$2 trillion a year by 2050. At the point of use, the only waste product from burning hydrogen is water vapour, but to serve as a low emissions fuel there must be virtually no emissions in the process used to produce it. The only way that customers will know that to be the case is if there is an internationally agreed certification system. Such a system will also put producers under pressure because no customers will buy hydrogen in future that isn't produced through a low emissions process. Safety is an issue, but no worse than for other fuels. Cost is an issue, but costs will be driven down as production volume increases and through incremental improvements in the efficiency of fuel cells and electrolysis. The biggest challenge in the shift to the hydrogen economy is to make the leap from demonstration projects to commercial ones.

Thinking about the challenges for today's meeting, I could not help but reflect on the dreams of the past 150 years. Dreams full of promise, not yet delivered. Why is today's dream different from all the earlier dreams?

In 1874, Jules Verne wrote a science-fiction novel called *The Mysterious Island*, in which the hero, Cyrus Harding, waxed lyrical about hydrogen.

"Yes, but water decomposed into its primitive elements," replied Cyrus Harding, "and decomposed doubtless, by electricity, which will then have become a powerful and manageable force … Yes, my friends, I believe that water will one day be employed as fuel, that hydrogen and oxygen which constitute it, used singly or together, will furnish an inexhaustible source of heat and light, of an intensity of which coal is not capable. Someday the coal-rooms of steamers and the tenders of locomotives will, instead of coal, be stored with these two condensed gases, which will burn in the furnaces with enormous calorific power."

PHOTO: Office of the Chief Scientist

In 1923, British biologist JBS Haldane painted his vision for a renewable energy economy powered by "rows of metallic windmills" producing electricity for "electrolytic decomposition of water into oxygen and hydrogen" that would be stored, then recombined in "oxidation cells" to produce electricity when needed.

We were there again in the 1970s, when the oil shock helped to popularise the hitherto fringe ideas of John Bockris, an American academic based at Flinders University in South Australia. It was Bockris who coined the term "hydrogen economy", and Bockris who brought the concept into the academic mainstream at the first global Hydrogen Energy conference in 1974.

You remember the story of the boy who cried wolf. Why should the politicians, businesses and consumers believe the message this time round? Because a lot has changed. It is up to us to explain it, to take the fiction out of science fiction, and focus on the science. And we have to do so based on a mix of proven achievement and yet-to-be-fulfilled ambition.

The importance of the energy transition that we will be part of cannot be overstated. Nothing is more essential to civilisation than energy. In 2003, Richard Smalley, who in 1996 won the Nobel Prize in Chemistry for discovering a spherical form of carbon called Buckminsterfullerene, published his list of the top 10 problems facing humanity. Top of his list was energy, followed by water and food.

But energy production and energy use contribute massively to carbon dioxide emissions and thus climate change. For example, in Australia, more than 75% of our emissions are in the energy-intensive sectors – electricity, transport, heating and fugitive releases. Thus, for the best return on effort, it makes great sense to focus on decarbonising these sectors.

> ***"Nothing is more essential to civilisation than energy"***

Ultimately, we can get all our primary energy from zero emissions electricity through solar, wind, hydro and perhaps nuclear. However, although electrons are versatile, they are not always the best way to use that energy. We need storage, and we need a transportable fuel to replace oil and gas. Nothing could be simpler, more capable, or cleaner than hydrogen to deliver these capabilities.

So, what has changed since the dreams of Jules Verne, JBS Haldane and John Bockris? Why has the Japanese Government asked the IEA to prepare a comprehensive study on hydrogen energy and economics as a key input to the G20 Ministerial Meeting in June this year? Three things have changed and converged to make the dream achievable.

First, we are in the midst of a growing determination to decarbonise our societies. It is a determination shared by most countries, many represented here today. But Japan gets a special mention: 94% of all its energy is imported coal, oil and natural gas. Japan needs a breakthrough solution, and by using hydrogen as an alternative fuel Japan will go a long way to decarbonising its economy.

Second, plummeting production costs, especially solar and wind, to generate the electricity for electrolysis.

Third, plummeting utilisation costs, especially in fuel cells. The price to produce fuel cells dropped by a factor of 20 between 2008 and 2015, and has continued to fall since then.

Making it work will require international partnerships. Every country has different needs and unique offerings to contribute. Take Japan and Australia. Japan is interested in importing hydrogen. Its first domestic uses will be for electricity generation and transport. Australia is interested in becoming a hydrogen exporting nation. Our first domestic uses will be for heating and transport.

Dr Finkel refuelling a hydrogen car in Japan
PHOTO: Office of the Chief Scientist

In all cases, countries must consider:

- Safety in everything we do.
- The costs of production and utilisation.
- The smartest means of shipping sunshine internationally.
- Minimising the impact on our land and water supplies.
- Economic growth. Hydrogen utilisation can provide new jobs and new industries – Japan and the Republic of Korea have recognised this explicitly in their national hydrogen plans.

And, of course, for hydrogen to be a low emissions fuel, the production must also be associated with low net emissions. We cannot simply shift the emissions from the consumers to the producers. To avoid that, we need an internationally agreed threshold for the amount of carbon dioxide that can be emitted during production and still qualify to be called carbon-free hydrogen.

There are three things about the hydrogen economy that keep me awake at night. First, safety. But then I reflect on our decades of safe industrial use of hydrogen and I am confident we can manage this. Second, costs. But then I reflect on the stunning rate of cost reduction in solar and wind electricity generation and I am confident we can manage this. Third, the transition from demonstration projects to commercial projects. I reflect on the large and growing number of demonstration projects but the paucity of commercial projects and I toss and turn thinking about how to traverse the valley. It is our biggest challenge, and I am pleased it will be discussed extensively today.

Assuming we can make the leap to commercial scale, to meet the global future needs the volume to be produced is huge. The Hydrogen Council is predicting a hydrogen market of more than $2 trillion per year by 2050. Can we make enough? Cheaply enough? Yes, by scaling up, reducing the input costs for production, and adopting internationally agreed standards.

But we will also need research and development to deliver further efficiency improvements. Given the role of fuel cells in electricity generation and transport, every one percent improvement in fuel cell efficiency will save tens of billions of dollars. Every one percent improvement in electrolysis efficiency will save tens of billions of dollars. Ongoing investment in research and development will pay back the investment many times over. We've done this in other industries. Many of you will have followed the stunning improvements in the efficiency of light-emitting diodes, which have gone from being less efficient than a candle when I started Electrical Engineering more than 40 years ago to outshining every other form of lighting today.

"We need to move past the false dichotomy of low prices or low emissions; our unrelenting ambition should be to have both"

Lastly, as we decarbonise our economies, we need to move past the false dichotomy of low prices or low emissions; our unrelenting ambition should be to have both. We need to embrace change for economic advantage and environmental advantage. By embracing change and new technologies we can have our cake and eat it too.

Buckminster Fuller, the famous architect, inventor and futurist, after whom buckminsterfullerene was named, said it best: "You never change things by fighting the existing reality. To change something, build a new model that makes the existing model obsolete." Let's build that new model, through vision, determination and international cooperation.

26. Shipping Sunshine at Scale

April 29 2019 | US Department of Energy Hydrogen and Fuel Cells Program Annual Merit Review and Peer Evaluation meeting in Washington

> The world is clamouring for hydrogen. Like the fossil fuels of today, hydrogen will be shipped between the continents. But if hydrogen is to meet its potential, production must be massively scaled up. The Global Hydrogen Council anticipates annual hydrogen consumption of 80 exajoules by 2050. If solar electricity is used to produce it, that means 10,000 gigawatts of new solar. Globally, 2020 capacity stands at about 600 gigawatts; another 600 gigawatts if you include wind. Big is something Australia is expert at; we are already the world's biggest exporter of iron ore and LNG. We also have space and sunshine in spades. And Australia is an early-adopter, with the highest percentage of homes with rooftop solar in the world. This makes us perfectly positioned for the hydrogen economy.

Let's start today with a trip to Australia. You drive to the airport, get on a plane and fly 10,000 miles to Sydney. Then you swap planes and fly 2000 miles west to Perth, swap planes again and fly another 1000 miles north. And then you get hold of a four-wheel drive and follow the rail line into the desert for about five hours. You're standing in the Pilbara.

You'll notice that it's very, very hot; it's very, very dry; and it's very, very remote. But it's also home to the world's biggest robot. And that's Rio Tinto's Mine of the Future. It's a sophisticated mega-machine taking a million tonnes of iron ore from pit to port every day, with 1000 miles of rail running fully autonomous trains, and autonomous dump trucks the size of two storey buildings. That mega-machine in the desert is one of the reasons we export more iron ore than any other country, with more than double the exports of Brazil.

If you drive back to the coast, then get on a helicopter and just keep going, you'll find yourself staring down at the Indian Ocean. What you'll see out the window is a hundred miles of choppy water, maybe the occasional Great White Shark, and then, the largest offshore floating facility ever constructed. A 600,000 tonne LNG production platform, manufactured in Korea and operated by Shell Australia. We've been developing the gas fields off the northwest coast of Australia for the past 30 years. And last year we took the crown as the world's leading exporter of LNG.

Is it hard to run giant robots in the desert and floating gas platforms in the sea? Yes. And when you factor in that we're a high wage economy, that we're a long way from a lot of key markets, and that we're scrupulous on environmental protections and safety, then the economics only work if you can operate at scale.

By scale, think big. Biggest-in-the-world scale. Biggest-ever-attempted scale. That scaled-up thinking is what I want to focus on today – a sense of the incredible opportunity in reach.

* * *

So let's start with the big picture: zero emissions energy everywhere, for everyone. How do we get there? The answer, in a word, is electrification. In a sentence, we replace the fossil fuels in electricity production with solar, wind and hydroelectricity, and possibly nuclear electricity; then we massively increase the production of clean electricity, and use it to replace the fossil fuels everywhere else. That is, we build the Electric Planet.

> ***"We need to move past the false dichotomy of low prices or low emissions; our unrelenting ambition should be to have both"***

Now electricity is incredibly versatile, but as you in the audience here today know better than anyone, it's not enough. We need a way to ship the sunshine internationally, we need seasonal storage, we need fuel for heavy transport. And so we need the carrier, hydrogen – hydrogen for energy, at scale.

What does that look like come 2050? McKinsey's 2017 report for the Global Hydrogen Council set out a vision of 80 exajoules of hydrogen consumption per annum. Let's accept this figure, and further, for the sake of the discussion, let's assume that the world exclusively uses solar photovoltaics, in good locations, to produce all of this hydrogen, and that the losses in production, compression and distribution are 50% in total. On my calculations, acknowledging that the hydrogen replaces some of the electricity that would otherwise be used directly in the Electric Planet, we'd need just over 10,000 gigawatts of additional solar electricity capacity to produce the 80 exajoules. Ten thousand gigawatts.

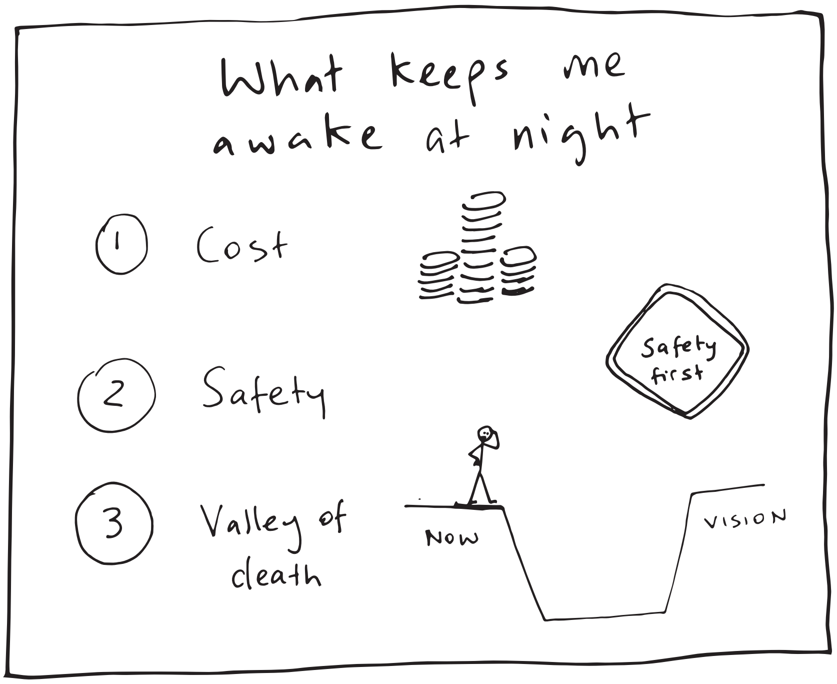

PHOTO: US Department of Energy

How many gigawatts of solar capacity have we installed around the world thus far? About 400 gigawatts [by late 2020, capacity had increased to 600 gigawatts]. Wind and solar together are just over 1,000 gigawatts. The most solar and wind capacity we've ever installed in a single year is 140 gigawatts. Now, picture that, just for making hydrogen, 72 times. If we continue to imagine that all that future electricity to make hydrogen comes from solar, then in terms of land area, using current technology, that's a solar farm the size of Wyoming. A lot of effort! But a lot of value.

If that 80 exajoule vision is achieved, then we're looking at US$1.3 trillion of global hydrogen sales come 2050. An industry of this magnitude provides an extraordinary multiplier on return for effort. For instance, you might be the engineer who scrapes away for a decade for what looks on paper like a tiny improvement, but in a mega-scale market, every increment counts.

Let's say that all the 2050 hydrogen comes from electrolysis. A one percent efficiency gain in electrolysis saves US$13 billion per year. Or say that half the 2050 hydrogen is to be used in fuel cells. A one percent efficiency gain in fuel cells saves US$7 billion per year. That means that the work done by the world's best technologists – and I'm looking at you, right here in this room – will repay investors in spades.

And if you're excited by scale, Australia is excited by scale, because if any country is blessed with buckets of sunshine and years of producer experience, trust me, it's Australia. On my calculations, if Australia were to export as much energy in the form of hydrogen as we currently export in the form of LNG, then we'd need 880 gigawatts of new-build solar, covering just over 4000 square miles. In Australian terms, that's about half the size of our biggest cattle station. So, yes, it's a big requirement, but we're used to thinking on that scale; and phased over 30 years, it's absolutely conceivable.



To fulfil the potential, we need commitment. That's why I'm here, as the head of the national taskforce commissioned by every government in Australia, state and federal, to develop our National Hydrogen Strategy.

As it happens, we're currently in the midst of national elections. It's the first time, to my knowledge, that either of our major parties has gone to an election talking about hydrogen. This time, it's both. Our leaders are alive to the promise of this agenda.

So, there's the case for the affirmative, the reasons for optimism. But what you really want to know is the case for the negative – what wakes me up at night. I'd say there are three things.

The first is cost. Japan has named the target: price parity with the landed cost of LNG. That's tough, but then again, that's exactly what I would have said 10 years ago if you'd asked me if new-build solar could get to parity with coal. And in many places today, it's not at parity – it's already cheaper. To meet the Japanese landed cost target for hydrogen, the electricity to produce it will have to be comfortably below US$10 per megawatt hour, without subsidies. So yes, we have to keep that cost target firmly in mind, but like it has done before, the market will find a way. And I can go back to sleep.

The second thing that wakes me up at night is safety. Hydrogen has to be safe, and be seen to be safe by consumers. And that comes down to good regulations. Good regulations aren't a constraint. Good regulations are a CEO's best friend. If you've got clarity and the community has comfort, then investors will have confidence. Both the United States and Australia have outstanding safety records when it comes to handling natural gas. The risks associated with hydrogen are different, not greater. And they can be managed. So I can go back to sleep.

That brings me to the third thing that wakes me up at night. I'll be honest, I close my eyes and I see the Valley of Death. The Silicon Valley Valley of Death. On the far side of the valley I see the hydrogen economy of 2050. Freeways lined with refuelling stations. Half a billion hydrogen cars, buses and trucks. Thousands of square miles of solar PV. A million forklifts powered by Plug Power fuel cell systems. Hundreds of hydrogen carrier ships criss-crossing the globe. It's glorious.

And then I look at the terrain right in front of me. And somehow, you and I and all of the pioneers who can see that brilliant future so clearly, have got to rally our people to hitch up the wagons, and trudge down that slope. And through the canyon. And up the other side. Whichever way I look at it, it's daunting. So, can I go back to sleep? I'm still deciding.


PHOTO: US Department of Energy

But there are two thoughts I'd invite you to consider. The first is that the Valley of Death isn't a gap to be jumped in a single flying leap. It's a journey to navigate on multiple paths. That means being prepared to build out gradually, learning and recalibrating along the way.

For example, cracking the tough nut of moving hydrogen around the world. Yes, we can build pipelines, but we can't easily build a 4000 mile pipeline under the ocean from Darwin, Australia, to Tokyo, Japan. We need ships. Now I'd be delighted if a big investor would wake up tomorrow morning and decide to drop US$10 billion on a hydrogen port and liquefaction facility in Australia. And maybe throw in another US$50 billion for 200 liquid hydrogen tankers to improve on the current global total of zero. Not going to happen.

But what we can do today is make and ship ammonia. So we can start there, where regulators and investors have experience, and gradually open up the pathways for global trade. We can take the same approach in the other big and interconnected systems we need to develop, be it systems and new technology for long-haul trucking, or electricity generation, or hydrogen in the domestic gas mains.

It's a global effort. It's still a race. It's a race against time, and against each other. But it's the sort of race that can generate the momentum to push everyone forward if we build on the emerging vision among experts in the United States, Europe and Asia for a decarbonised energy supply; if we draw in private investment; if we collaborate as well as compete; if we develop the supply chains; and if governments make it a priority.

So that's my first thought for this audience. The trudge through the valley may be gruelling, but you're not alone, there are many viable paths and even your competitors are on your side.

My second thought is to encourage you to reach out to Australia. What Australians see in America is a country that understands the challenges of scale. A country that's almost incapable of starting small without a plan to go big. So, when you look at Australia, I want you to see your at-scale laboratory. We've got lots of space, lots of energy and lots of expertise. Talk to us early, at the demonstration phase. We'll take the call.

I also want you to look at Australia and see a nation of early adopters. In no other country will you find a higher percentage of homes with rooftop solar. So choose Australia for your pilot program, or look for opportunities to sell and support your products.

And indulge me on just one more imaginary trip. It's 2050. You're flying over the heartland of Australia. Who knows what sort of aircraft, but whatever it is, it's impressive. And you look out over that great sunburnt country, and spread out before you is the world's biggest hydrogen farm. Australian sunshine. Global technology. And I hope you're seeing it with me – the realisation of your ideas, at scale. That's where we're headed, so reach out to us to find your path.

And, as chief scientists are allowed to say at the end of every speech, may the Force be with you.

27. Hydrogen Safety, at Scale

September 24 2019 | Speech at the International Conference on Hydrogen Safety

Think of the energy sources we take for granted that would struggle to be approved for sale if they entered the consumer market today: petrol, electricity and natural gas. We have learned to reap the benefits and manage them safely. Each of them is different. So, too, with hydrogen. It is already in widespread industrial use and now in growing commercial and consumer use. It is reliable and secure because regulators and operators have invested for many years in the development of appropriate regulations and operating procedures. We must ensure that safety is preserved as hydrogen enters widespread production and use in the coming decades. To earn public trust and support, it must also come with absolute transparency. In November 2019, the Australian Government and all State and Territory Governments adoped the National Hydrogen Strategy prepared by the Hydrogen Working Group, which I chaired. It considers benefits, risks, and barriers to using hydrogen.

Before looking to the future, I want to take you back to 1946. Sir Douglas Mawson, the famous explorer, is here in South Australia serving as a professor at the University of Adelaide. In between his professorial duties, Mawson is waging a campaign to establish a permanent Australian presence in Antarctica.

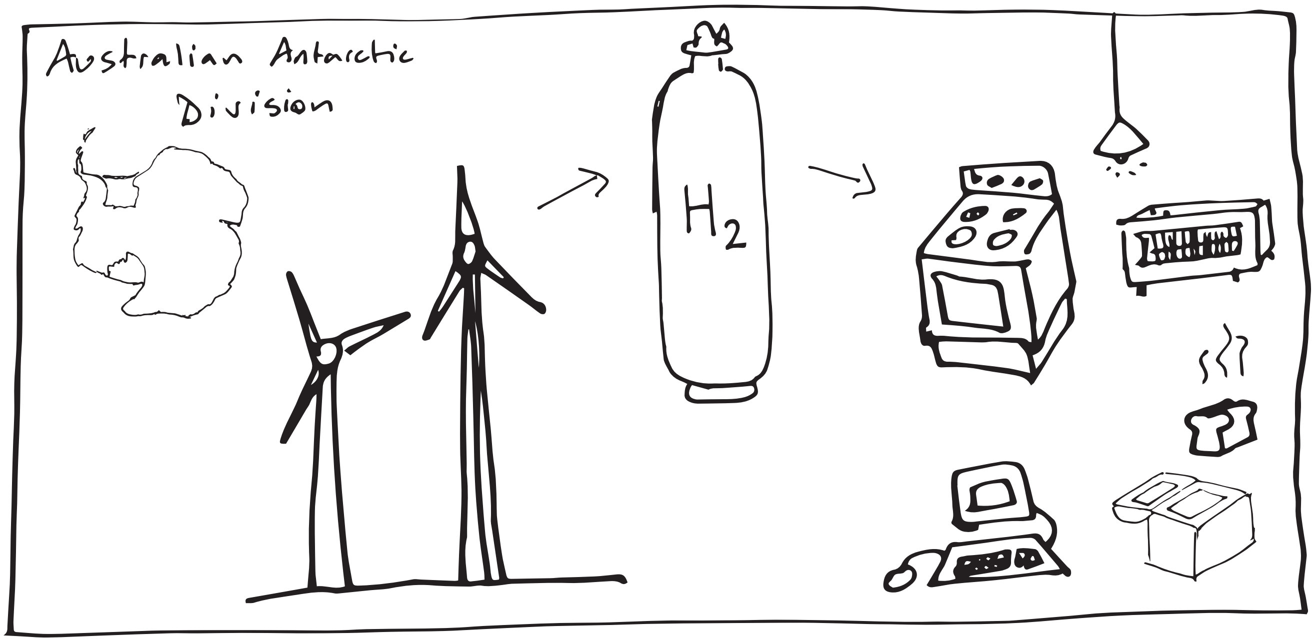
"As proprietors of so large a slice of the south," Mawson declares, "we owe to the world, and for our own benefit … to find a suitable site for a permanent base … [and] carry out scientific work which should be of great value to Australia."

Mawson's activism succeeds and in 1948 the Australian Antarctic Division is born. Just six years later, under the leadership of explorer and scientist Dr Philip Law, the Australian Antarctic Division fulfils Mawson's vision and establishes the first permanent research base on the Antarctic continent, naming it in his honour. Dr Law notes that Mawson Station could become "an arena … to demonstrate [Australia's] scientific and technological excellence".

But what does this have to do with hydrogen Alan? I hear you asking. Well, the incredibly hostile environment in which our Antarctic researchers live and work means a significant amount of fuel is needed to support their endeavours. In 2000, more than two million litres of diesel fuel were used to provide power and heating to stations operated by the Australian Antarctic Division – and the purchase, transportation, and storage of such vast amounts of fossil fuel entail significant economic costs and environmental risks.

But what to do? When I was a child, I read a suspense novel called Ice Station Zebra, by Alistair MacLean, in which the hero, spy agent Dr Carpenter, is trying to locate and rescue the team of an Antarctic weather station that had been gutted by fire. This book forever cemented in my mind the danger associated with using fuel and electricity in Antarctica. As he is about to embark on his mission, Dr Carpenter laments "with their fuel oil reserves completely destroyed and their food stores all but wiped out, it is feared that those still living cannot long be expected to survive".

If only they had the enterprising team of the Australian Antarctic Division by their side! In 2005, using energy from wind turbines, and through the process of electrolysis, the Australian Antarctic Division was able to generate renewable hydrogen in Antarctica and transport it in cylinders using a hydrogen-powered quad bike. The hydrogen was then used to power the everyday activities of Australia's Antarctic scientists on Mawson Station, fuelling cooking stoves and generating electricity to run heaters, lights, computers and even a bread-maker.



What a staggering feat of ingenuity, proving that even in the coldest, darkest, most hostile continent on Earth, where special materials and construction techniques are often required, hydrogen energy can be safely and effectively harnessed for human benefit. That way of thinking, that spirit of curiosity and innovation and the willingness to challenge boundaries of science and technology – to try, and fail and then try again – it's all part of the process of discovery. It's what has spurred countless advances and benefits for our society.

And yet, as the march of technology continues to present greater benefits, it also presents greater hazards than ever before. Take my day for instance. In getting ready for today's conference, I woke up and turned on my kettle to make a cup of tea. Feeling a headache coming on, I took a paracetamol (acetaminophen for our US friends), then had a shower, got dressed, walked downstairs and drove from my hotel to this convention centre. Finally, seeking a quick energy hit before my presentation, I bought a chocolate bar from the vending machine. On the face of it, a pretty mundane morning.

But the reality is that these simple activities, which are firmly embedded in our everyday lives, all have some degree of risk associated with their use. Paracetamol is the substance most frequently involved in overdoses in Australia, with 10,000 people hospitalised and more than 20 people dying from paracetamol poisoning every year. Turning on my kettle and taking the stairs might appear innocuous, but faulty appliances account for 60 house fires a week in the UK, and in 2017, 77 Australians died from falling down the stairs or tripping on a step. Driving my car was positively reckless, with more than three people a day killed on our roads. And as for my chocolate bar from the vending machine? According to the US Consumer Product Safety Commission, on average two people a year are crushed to death by toppling vending machines. And yet here I am, alive and well.

"In Australia we proudly have some of the highest safety standards in the world, which has garnered the trust of the Australian people as new technologies and innovations are introduced"

As a society, we understand that accidents do, of course, happen, but we rightly expect our standards and codes to mitigate these risks as much as possible. And here in Australia we proudly have some of the highest safety standards in the world, which has garnered the trust of the Australian people as new technologies and innovations are introduced. Indeed, a study conducted last year by University of Queensland found that three in every four Australians trust our regulations and standards will enable the development of a safe hydrogen industry. Our challenge, therefore, is to live up to these standards and community expectations.

Decades of experience and continuing progress in technologies have shown that hydrogen power is reliable and secure. From ammonia production, to petrochemical refineries, to metals processing, to chemical, food, and glass manufacture, the safety record of hydrogen in this country is exemplary. I am confident that this record can be maintained as we seek to open new frontiers and expand our energy horizons.

As Chair of the Council of Australian Governments' Hydrogen Working Group, I can report that we are currently developing our National Hydrogen Strategy by examining five areas of opportunity.

First, analysing the benefits, risks, and barriers to using hydrogen as a transport fuel in Australia by 2030.

Second, the interplay between hydrogen production and electricity system operation, and the opportunities for clean hydrogen production and storage to contribute to the resilience of Australia's electricity systems.

Third, analysing the challenges and issues related to introducing hydrogen into Australia's gas distribution networks, and examining the actions needed to start blending hydrogen into these networks.

Fourth, exploring opportunities for developing an export market for Australian hydrogen with partner countries.

And finally, investigating opportunities for hydrogen as a chemical feedstock and source of industrial heat.

I am, therefore, acutely aware of the unparalleled possibilities this source of power can unleash. However, I am also aware, and I firmly believe, that its benefits across all areas will only be realised by a wholehearted commitment to safety and transparency, and our ability to bring the Australian community along on the journey. To maintain the trust of the Australian people, every effort must be made to protect public health and safety and to provide straightforward answers to any legitimate concerns about producing hydrogen at scale. We must also ensure the process of determining the safety and environmental standards of hydrogen is more extensive and more accessible to the public than for any comparable enterprise. We must, in short, pay attention to every aspect of hydrogen safety – from down in the weeds, right up to the tree tops – and encourage everyone to get involved in this endeavour.

> ***"To maintain the trust of the Australian people, every effort must be made to protect public health and safety and to provide straightforward answers to any legitimate concerns about producing hydrogen at scale"***

Indeed, we have already seen how embracing a spirit of partnership across sectors, and enhancing public understanding of hydrogen, can reap benefits. In the state of California, through a creative collaboration of automotive companies, energy providers, developers and government agencies, the California Fuel Cell Partnership has established a self-sustaining market for hydrogen fuel cell vehicles, underpinned by a commitment to safety and transparency. Through exhibits, vehicle demonstrations and presentations to schools, conferences and community stakeholders, the partnership ensured the public understood and felt comfortable with hydrogen technology prior to its introduction.

Crucially, the partnership also joined forces with the Pacific Northwest National Laboratory to develop and deliver hydrogen safety-related emergency-services training materials and programs. As Hydrogen Safety Program manager at the Pacific Northwest National Laboratory and now Director of the Center for Hydrogen Safety Nick Barilo, who is here with us today, noted, "part of the training is to remove the stigma; people don't understand what hydrogen is all about". Through more than 10,000 sessions, emergency responders were educated on the safety features built into hydrogen fuel cell vehicles, as well as what to expect when they arrive at the scene of a crash.

The fruits of this labour are there for all to see, with Californians owning more hydrogen fuel cell vehicles than any country in the world. The numerous hydrogen stations along California's highways offer a glimpse of how a comprehensive, coordinated approach can lead to a large, rapid growth in hydrogen demand.

This success also illustrates one of the most important principles of good safety regulation, little understood by the public but fully understood by experts like yourselves. The principle is that we can have our cake and eat it too. More specifically, what I mean is that good safety regulation should simultaneously ensure the safety of the public and facilitate commerce. Which is why I am delighted that Australia will be joining the Center for Hydrogen Safety, exploring how our emergency services personnel can leverage the expertise of Nick and his team. By working together, we will further advance our collective goal of not only maximising safety but also enabling the industry to thrive by doing so.

Indeed, ensuring this goal is realised has been the focus of this conference since it was first held in 2005. At that first conference in Pisa, Italy, members declared their intention "to improve and co-ordinate the knowledge and understanding of hydrogen safety, [and] foster a sound basis for the removal of safety-related barriers to the implementation of hydrogen as an energy carrier".

The growth of conference participants over the subsequent years is proof of the success of that objective, as is the global recognition of HySafe as a centre of industry expertise. In Europe, in particular, your efforts have been instrumental in 25 European Union countries declaring their support for sustainable hydrogen technology, as well as securing EU funding of more than €100 million for hydrogen-related projects. Closer to home, the Government here in South Australia has been an active member of HySafe since 2018. It is testament to the vision and sustained action of successive South Australian governments and its public service that the Festival State is now an established world leader in the transition to a cleaner and more energy-efficient future.

PHOTO: Department for Energy and Mining

Hosting this conference for the first time ever on our shores underlines this commitment as we nurture hydrogen's role in a sustainable energy system, and ensure safety underpins all elements in its development. The findings, information, and data presented by the world's best hydrogen safety experts over the next three days will be invaluable to the pioneering work that lies ahead of us and I encourage you to reach out to members of our taskforce who are here with us today.

Our nation's capacity to utilise new industries and technologies to overcome our greatest challenges has driven our success as a nation – an Australia that lives and dies by its standards and quality brand. From Antarctica to the mainland, our nation's story is replete with visionaries who reach for the frontier where exploration and discovery begin, who test the limits of human endurance and technology in their unyielding effort to turn a curiosity into concrete results.

That same spirit can usher in a new national industry that will protect our environment, expand our economy and create thousands of jobs, in a safe and efficient way. The time to act is now, to seize the moment. By working together to ensure the highest standards of safety, we can turn the long-held dream of clean hydrogen contributing to our energy needs into a reality, and inspire a new generation of innovators, dreamers and doers. This conference is the perfect forum to safely journey along the next chapter in that dream.

May the Force be with you.

28. The Orderly Transition to the Electric Planet

February 12 2020 | Keynote Address to the National Press Club

The Australian bushfires of 2020 were a reminder, if it were needed, that the crisis of global warming is urgent. We have no choice but to reduce carbon dioxide emissions, and quickly. More than three-quarters of global carbon dioxide emissions come from energy for transport, heating, industry and traditional electricity generation. These things can't be abruptly turned off, making the transition to low emissions the biggest engineering challenge ever undertaken. I have a dream that all the world is powered by clean electricity – including for transport, building heating and industry. I call this the Electric Planet and I have been publicly speaking and writing about it since 2012. While solar and wind are being scaled up to supply the Electric Planet, natural gas has a place to firm up the supply of solar and wind electricity, making it possible for countries to transition to a reliable, relatively low emissions electricity supply as quickly as possible. But that won't solve all our problems. As versatile as they are, electrons are not always the best way to deliver energy. Sometimes we need a high density fuel to power ships and long distance trucks, sometimes we need a way to export energy between the continents, sometimes we need a feedstock to make ammonia for fertilisers. This is where hydrogen enters the picture. This speech was delivered to the National Press Club in early 2020 after the release of the National Hydrogen Strategy, and as work was beginning on the Low Emissions Technology Statement.

When I was growing up, one of the formative images that seared itself on my brain was a picture taken by the astronauts of Apollo 11. It was a picture of Earth, one of the first full-colour perspectives of our planet. A wondrous ball of bright blue, lightly veiled with swirling white clouds, peeking out of the eternal darkness of space.

Of course, that photograph highlighted another aspect of our existence – our fragility. Growing up in the 1960s we lived with the possibility that our beautiful planet would be wiped out in unconstrained nuclear war.

View of the Moon Limb, with earth on the horizon July 20 1969
PHOTO: NASA/JSC

The United States and Soviet Union had armed themselves with enough nuclear weapons to obliterate the human race several times over, with both sides publicly committing to immediate retaliation in the event of a first strike. The only outcome of such a defence would be mutually assured destruction. With the stunningly appropriate acronym, MAD.

For years, the terrifying prospect was that the image in that photograph, that blue marble containing all we know and cherish, could vanish in a single flash of light. A single moment of MAD-ness. Such was the fear, that a young American wrote to President Kennedy: "I am 11 years old and every night I worry. What will be left of this wonderful world if someone presses the button? What will be left of you and your family?"

Late last year, I received my own letter from a child. My 10-year-old grandniece, Elise, wrote to me: "Uncle Alan, I just watched a frighteningly real video on the crisis of sustainability. I would love it if you could talk to my school about what we can do, how we can help, and what is actually going on."

Now, there is a world of difference between nuclear war and climate change, but we cannot deny that for the next generation, climate change is one of their biggest concerns when contemplating the future. Elise, I'd like to reassure you that just as mutually assured destruction was supplanted with mutual international cooperation, so too can we take collective action on climate change. And so, Elise, as Australia's Chief Scientist, I take this opportunity to outline the science of climate change, and how we can use science and technology to address it.

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Around the time we started exploring space, scientists began to monitor and study the Earth's atmosphere. In the 1970s, the CSIRO and the Bureau of Meteorology created a joint research station at Cape Grim, in Tasmania, and began sampling the most pristine air in the world. And what they have recorded is an unrelenting increase in the levels of carbon dioxide in our atmosphere.

At the start of the Industrial Revolution, it was 280 parts per million. Today the concentration is 409 parts per million, a level not experienced for four million years – a time pre-dating humans, when giant sloths and mastodons roamed the Earth. And there is absolutely no hint of a slowdown. Annual carbon dioxide emissions from human activities increased from 24 billion tonnes in 1998 to 37 billion tonnes in 2018, and the atmospheric concentration rise last year was one of the highest annual increases ever.

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Our understanding of how these emissions impact our planet dates back almost 200 years, to 1824, when an extraordinary French mathematician, Joseph Fourier, whose work continues to shape engineering today, asked a simple question, as scientists often do: what is regulating Earth's temperature?

Fourier's answer was that the atmosphere was keeping the Earth's surface warm, like the glass windows in a greenhouse, hence the term "the greenhouse effect". Although the process is more complicated than that, Fourier provided a straightforward analogy that is still widely used.

In 1896, a Swedish chemist named Svante Arrhenius went a step further and determined the underlying physics of how global warming actually works. As the sun shines through our atmosphere, the Earth's surface warms and emits some of the sun's energy as infrared radiation. Ordinarily, this infrared radiation would escape to space. However, Arrhenius found that some gases, like carbon dioxide, trap this infrared radiation and then re-emit it in all directions. While some of that re-emitted infrared radiation makes its way back into space, the rest heats the Earth's atmosphere, surface and oceans, making them warmer than they would otherwise be.

We depend on these greenhouse gases to support all life on Earth. Without them, the Earth would lose so much heat that life as we know it would be impossible. The problem we are addressing occurs when greenhouse gas levels get too high because of human activities, trapping too much of the sun's energy as heat. This is referred to as the enhanced greenhouse effect.

And the past decade was hot. Really hot. In fact, my 10-year-old grandniece Elise has already lived through seven of the hottest years in recorded Australian history.

> ***"It is important to recognise that global warming is just that, global"***

It is important to recognise that global warming is just that, global. No nation is immune to its impact. Indeed, many nations that contribute the least to global warming are facing its most serious consequences.

Because ocean currents and major wind patterns respond to atmospheric and ocean warming, the effect of just one degree temperature rise causes major disruptions to the natural systems that regulate our climate. Small annual temperature changes eventually lead to tipping points, resulting in increasingly intense storms, deeper droughts, erratic swings in coastal water temperatures and consequent coral bleaching. These extreme weather events will not only persist but will be more severe, and in some cases more frequent, into the future.

Climate change is nature's reaction to our actions. It is real, and it is already happening with a rapidity that is deeply affecting our way of life. The link between climate change, a rising number of forest fire danger days and our season of bushfires is clear, and has resulted in a steep collective cost that can be measured in billions of dollars in economic damage — which pales to insignificance when compared to the greater costs behind the statistics. The lost lives and livelihoods. The lost businesses and homes. The lost flora and fauna. These costs are immeasurable, and I express my condolences here today to everyone affected by the devastating bushfire emergency this summer, especially all those who have lost loved ones.

Unless long term action is taken, these extreme bushfires conditions will be repeated, and indeed continue to worsen, into the future. We cannot wish it away. So, what can we do?

First, as the Prime Minister noted two weeks ago in this very room, "Practical action on mitigation through reduced emissions needs to go hand-in-hand with practical action on climate resilience and adaptation." Among many initiatives announced by the Commonwealth and state governments, including billions of dollars in support for bushfire relief, I have been asked by the Prime Minister to chair an expert advisory panel that will support the CSIRO in the development of advice to all governments on climate and disaster resilience.

Second, as Minister Karen Andrews has declared, as a nation we must move on from disputing the reality of climate change. As a global community, as agreed in Paris in 2015, and as we will see discussed in Glasgow later this year, we must work together on the next phase of emissions reduction.

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A practical mitigation approach is to address the biggest source of emissions. Nearly three quarters of global emissions come from energy used for transport, heating and industry, as well as traditional electricity generation. So, focusing on energy will present us the best return on investment.

But we cannot abruptly cease our use of energy. An energy supply is the most essential pillar of our civilisation. Without an energy supply, it's back to the Stone Age. Just think about the past 300 years since the invention of the steam engine. Everyone in this room is a beneficiary of energy-driven conveniences that make our daily lives easier and more productive.

Given this, the only way to meet the energy needs of the future without sacrificing standards of living or undermining the economy is by planning for an orderly transition that embraces science and technology as the stepping stones to the future we want. A future where we supply the vast majority of our energy requirements by electricity. Clean electricity. Not just for lighting, computing and air conditioning, but for transport, building heating and industry, too. A future I like to call the Electric Planet.

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I want you to imagine a highway exclusively devoted to delivering the world's energy. Each lane is restricted to trucks that carry one of the world's seven large scale sources of primary energy – coal, oil, natural gas, nuclear, hydro, solar and wind. Our current energy security comes at a price, the carbon dioxide emissions from the trucks in the three busiest lanes, the ones for coal, oil and natural gas. We can't just put up roadblocks overnight to stop these trucks; they are carrying the overwhelming majority of the world's energy supply. But, what if we expand clean electricity production carried by the trucks in the solar and wind lanes — three or four times over — into an economically efficient clean energy future.

Think electric cars instead of petrol cars. Think electric factories instead of oil-burning factories. Cleaner and cheaper to run. A technology-driven orderly transition. Problems wrought by technology, solved by technology. Make no mistake, this will be the biggest engineering challenge ever undertaken. The energy system is huge, and even with an internationally committed and focussed effort the transition will take many decades.

It will also require respectful planning and retraining to ensure affected individuals and communities, who have fuelled our energy progress for generations, are supported throughout the transition. As Tony, a worker from a Gippsland coal-fired power station, noted from the audience on this week's Q&A program [ABC TV 10 February 2020]: "The workforce is highly innovative, we are up for the challenge, we will adapt to whatever is put in front of us and we have proven that in the past." This is a reminder that if governments, industry, communities and individuals share a vision, a positive transition can be achieved.

PHOTO: Mark Graham

The stunning technology advances I have witnessed in the past 10 years make me optimistic. Renewable energy is booming worldwide, and is now being delivered at a markedly lower cost than ever before. In Australia, the cost of producing electricity from wind and solar is now around $50 per megawatt hour. Even when the variability is firmed with storage, the price of solar and wind electricity is lower than existing gas-fired electricity generation and similar to new-build coal-fired electricity generation. This has resulted in substantial solar and wind electricity uptake in Australia, and, most importantly, projections of a 33% cut in emissions in the electricity sector by 2030, when compared with 2005 levels. And this pricing trend will only continue, with a recent United Nations report noting that, in the past decade alone, the cost of solar electricity fell by 80%, and is set to drop even further.

So we're on our way. We can do this. Time and again we have demonstrated that no challenge to humanity is beyond humanity. But we cannot be naive about the scale of the task ahead, nor can we afford to discard any of the tools at our disposal. I have always maintained that the focus needs to be on outcomes. The outcome in this case is reduced atmospheric emissions. We should use whatever underlying technologies achieve the goal. Different nations will have different energy mixes and needs, but what does the generation technology matter if the outcome – atmospheric emissions – is lowered?

> ***"Time and again we have demonstrated that no challenge to humanity is beyond humanity"***

Nevertheless, in Australia, with nuclear energy and new hydroelectricity facing significant public opposition, we are theoretically limited to fitting all our future energy traffic into just two lanes – solar and wind. But, there is a limit to how much solar and wind we can use and still retain a reliable system. Ultimately, we will need to complement solar and wind with a range of technologies such as high levels of storage, long-distance transmission and much better efficiency in the way we use energy.

But while these technologies are being scaled up, we need an energy companion today that can react rapidly to changes in solar and wind output. An energy companion that is itself relatively low in emissions, and that only operates when needed. In the short term, as the Prime Minister and Minister Angus Taylor have previously stated, natural gas will play that critical role.

In fact, natural gas is already making it possible for nations to transition to a reliable and relatively low emissions electricity supply. Look at Britain, where coal-fired electricity generation has plummeted from 75% in 1990 to just 2% in 2019. Driving this has been an increase in solar, wind, and hydro electricity, up from 2% to 27%. At the same time, and this is key to the delivery of a reliable electricity supply, electricity from natural gas increased from virtually zero in 1990 to more than 38% in 2019. Closer to home, look at South Australia's success in increasing solar and wind electricity to 51% in the last fiscal year. Again, natural gas is key to the stability of the electricity supply, accounting for 47%.

I am aware that building new natural gas generators may be seen as problematic, and I will come back to that, but, for now, let's assume that with solar, wind and natural gas, we will achieve a reliable, low emissions electricity supply. Is this enough? Not really. We still need a high-density source of transportable fuel for long distance, heavy-duty trucks. We still need an alternative chemical feedstock to make the ammonia used to produce fertilisers. We still need a means to carry clean energy from one continent to another. Enter the hero, hydrogen.

* * *

Hydrogen is abundant. In fact, it's the most abundant element in the universe. The only problem is that there is nowhere on Earth that you can drill a well and find hydrogen gas. Don't panic. Fortunately, hydrogen is bound up in other substances. One we all know – water, the H in H^2O.

> ***"Enter the hero, hydrogen"***

We have two viable ways to extract hydrogen with near-zero emissions. First, we can split water in a process called electrolysis, using renewable electricity. Second, we can use coal and natural gas to split the water, and capture and permanently bury the carbon dioxide emitted along the way.

I know some may be sceptical, because carbon capture and permanent storage has not been commercially viable in the electricity generation industry. But, the process for hydrogen production is significantly more cost-effective for two crucial reasons. First, since carbon dioxide is left behind as a residual part of the hydrogen production process, there is no additional step and little added cost for its extraction. And second, because the process operates at much higher pressure, the extraction of the carbon dioxide is more energy efficient and it is easier to store.

Returning to the electrolysis production route, we must also recognise that if hydrogen is produced exclusively from solar and wind electricity, we will exacerbate the load on the renewable lanes of our energy highway.

In my training as an engineer, I was taught to build safety margins and redundancy into critical systems. Now, you might say to me, Alan, we're never going to run out of sunshine and wind. But think for a moment of the vast amounts of steel, aluminium and concrete needed to support, build and service solar and wind structures. And the copper and rare earth metals needed for the wires and motors. And the lithium, nickel, cobalt, manganese and other battery materials needed to stabilise the system. What if there was a resources shortage?

It would be prudent, therefore, to safeguard against any potential resource limitations with another energy source. Well, by producing hydrogen from natural gas or coal, using carbon capture and permanent storage, we can add back two more lanes to our energy highway, ensuring we have four primary energy sources to meet the needs of the future – solar, wind, hydrogen from natural gas, and hydrogen from coal.

PHOTO: Mick Tsikas/AAP Image

Furthermore, once extracted, hydrogen provides unique solutions to the remaining challenges we face in our future Electric Planet. First, in the transport sector, Australia's largest end user of energy. Because hydrogen fuel carries much more energy than the equivalent weight of batteries, it provides a viable, longer-range alternative for powering long-haul buses, B-double trucks, trains that travel from mines in central Australia to coastal ports, and ships that carry passengers and goods around the world.

Second, in industry, where hydrogen can help solve some of the largest emissions challenges. Take steel manufacturing. In today's world, the use of coal in steel manufacturing is responsible for a staggering seven percent of carbon dioxide emissions. Persisting with this form of steel production will result in this percentage growing frustratingly higher as we make progress decarbonising other sectors of the economy. Fortunately, clean hydrogen can not only provide the energy that is needed to heat the blast furnaces, it can also replace the carbon in coal used to reduce iron oxide to the pure iron from which steel is made. And with hydrogen as the reducing agent the only byproduct is water vapour. This would have a revolutionary impact on cutting global emissions.

Third, hydrogen can store energy, not only for a rainy day, but also to ship sunshine from our shores, where it is abundant, to countries where it is needed. Let me illustrate this point. In December last year, I was privileged to witness the launch of the world's first liquefied hydrogen carrier ship in Japan. As the vessel slipped into the water I saw it not only as the launch of the first ship of its type to ever be built, but as the launch of a new era in which clean energy will be routinely transported between the continents. Shipping sunshine.

The Suiso Frontier, the world's first liquid hydrogen carrier
PHOTO: Maho Obata

And, finally, because hydrogen operates in a similar way to natural gas, our natural gas generators can be reconfigured in the future to run on hydrogen, neatly turning a potential legacy into an added bonus.

We truly are at the dawn of a new, thriving industry. There's a nearly $2 trillion global market for hydrogen come 2050, assuming that we can drive the price of producing hydrogen to substantially lower than $2 per kilogram.

In Australia, we've got the available land, the natural resources, the technology smarts, the global networks and the industry expertise. And we now have the commitment, with the National Hydrogen Strategy unanimously adopted at a meeting by the Commonwealth, state and territory governments late last year.

Indeed, as I reflect upon my term as Chief Scientist, in this my last year, chairing the development of this strategy has been one of my proudest achievements. The full results will not be seen overnight, but it has sown the seeds, and if we continue to tend to them, they will grow into a whole new realm of practical applications and unimagined possibilities.

> ***"We truly are at the dawn of a new, thriving industry"***

The National Hydrogen Strategy provides a framework for Australia to cost-effectively become a world leader in this new industry. We have the potential to be one of the top three exporters of clean hydrogen, and to create an exemplary safety track record, thousands of new Australian jobs, especially in regional areas, and billions of dollars in economic growth between now and 2050. And we're on our way to meeting this goal.

State governments right around the country have introduced funded hydrogen action plans, departmental teams have been established to ensure their effective roll-out, and the Commonwealth Government has announced $370 million of hydrogen stimulus funding, including $70 million for an ARENA funding round already in motion. By building on this progress, Australia can simultaneously confront the environmental challenges threatening our nation and the world, while laying the groundwork for our long term economic security and prosperity.

I have every confidence we can do it. For we are Australians, born, in the words of Henry Lawson, “to be thinkers and doers, and makers of wonderful things”. We are resilient and bold and possess, as Dame Enid Lyons once noted, “qualities of initiative and daring that ... will never be allowed to die”. Our proven capacity for greatness, for courage to go beyond the seemingly impossible, is how we have led in the pursuit of new horizons; it’s how we have helped shape the world.

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I want to leave you today with one more letter, written by a man who left his small town to embark on a historic mission, which was helped, in part, by our nation’s ingenuity.

“Down in Australia,” the letter goes, “there were some very dedicated people ... instrumental in the success of man’s first flights to the moon. Science fiction writers thought it would be possible ... to get people to the moon. But none ... foresaw any possibility of the lunar explorers being able to ... transmit moving pictures of what they saw back to Earth. I was probably the most surprised person in the human race when Mission Control announced they were getting a picture. So I will just say thanks, mates. Neil Armstrong.”

Thanks to Australia’s radio telescope facilities in Parkes and Honeysuckle Creek, 600 million people around the world stood as one and watched the moon landing on their television screens – inspiring wonder and sparking passions in a new generation, including a young teenager in Melbourne who became enamoured with all things science and who stands before you here today.

The task of dealing with the challenge of climate change will require the same spirit of unity, enterprise and achievement. It will require each of us to believe in ourselves and in our ability to accomplish great deeds. To believe, that with imagination and technological innovation, and perseverance across decades, we will meet this challenge, and preserve the image in that photograph that seared itself on my brain all those years ago.

Long after the Apollo 11 mission, when astronaut Michael Collins was asked how it felt to take that photo, to see the Earth majestically rising above the lunar surface, he responded: “Oddly enough the overriding sensation I got looking at the Earth was, my God, that little thing is so fragile out there.”

Let us all reflect on this simple yet powerful message. We only have one precious planet to call home, and we all hold a great responsibility in our tenancy here, to children like Elise, and to generations yet to come.

29. Captain Hydrogen and its Derivatives

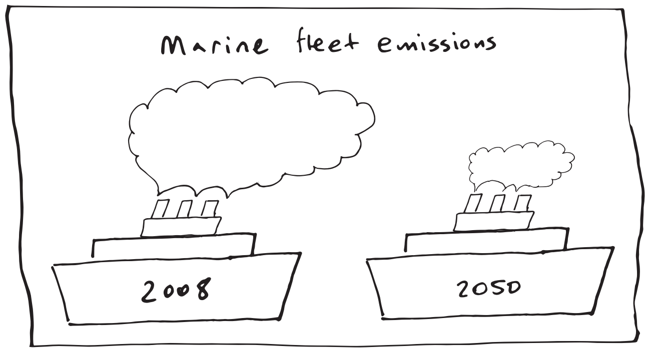
August 27 2020 | Opening remarks for the 2020 Ammonia Energy Association global forum

> Take some nitrogen from the atmosphere, combine it with clean hydrogen, and voila! Clean ammonia. Of course, it is a very different chemical to either of the two starting ingredients, but like hydrogen it stores a lot of energy, and it can also be used as an industrial feedstock, mostly to make fertilisers but also in cleaning solutions, and in the manufacture of dyes, plastics and explosives. There is considerable interest in using ammonia as an energy carrier to transport renewable energy in bulk from Australia to destinations around the world. The jury is out on whether liquid hydrogen or liquid ammonia will be used to transport solar and wind energy between continents. My guess is both. Equally exciting is the growing interest in using clean ammonia as a maritime fuel in modified diesel engines. Its advantages of simplicity of handling are currently balanced by the challenges of minimising nitrogen oxide emissions when the ammonia is burned, but this problem is being actively addressed and I am confident will be solved.

Sometimes people refer to me as Captain Hydrogen. I like that. I like cool titles, such as Australia's Chief Scientist. But actually, cool as it is, Captain Hydrogen is too narrow. It should actually be Captain Hydrogen and Hydrogen Derivatives. But that is too much of a mouthful!

The point is, clean hydrogen is not just important in its basic form but also in its derivatives, in particular ammonia. I must admit, up until a couple of years ago, I only thought of ammonia as the main ingredient in toilet cleansers. But my viewpoint has expanded from a small bowl of spiralling water to the expansive oceans of planet Earth. Today, the merchant ships navigating the oceans are responsible for nearly 3% of global emissions of carbon dioxide. And if the industry does not reform, the share of carbon dioxide emissions would grow as other sectors of the global economy improve.

As you know, in recognition of this, the International Maritime Organisation has set a goal to halve fleet emissions by 2050 based on 2008 levels. That's more difficult than it sounds because during the next 30 years the number of ships crisscrossing the oceans will increase. To achieve the target, most new vessels commissioned in coming years will need to have a zero emissions propulsion system. Simply shifting from bunker fuel to compressed natural gas would not be sufficient to halve the emissions. And for reasons I will not go into now, biofuels or synthetic carbon-based fuels are unlikely to ever be available in the quantity required.



That leaves clean hydrogen, or clean ammonia made from clean hydrogen. Comparing the two, both would work as a fuel, but there are some reasons why ammonia is likely to be preferable in shipping.

First, although it has a lower energy density by mass than hydrogen, it has a better energy density by volume. Volume is likely to be more of a consideration than mass.

Second, on-board handling is much easier, because ammonia can be kept in its pure liquid form at all ambient temperatures in tanks at just a few tens of atmospheres of pressure. Liquid hydrogen only exists at an incredibly low temperature, just 20 degrees above absolute zero where all the hydrogen molecules would stop vibrating. Thus, liquid hydrogen requires very sophisticated tanks and handling.

Third, international trade and stockpiling at hubs such as Singapore will be easier for ammonia than for hydrogen.

When considering the prospect of using ammonia as a maritime fuel, at first I thought that the ammonia would be used in fuel cells to generate electricity to drive electric motors. And it could be. But as it happens, it can be also used directly in modified marine diesel motors. That would be an incredibly easy and convenient transition. The main challenge is nitrogen oxide production – the so called NOx emissions – but I am confident that engine designers will solve that problem. I don't know how, but they will.

It is great to see that the shipping industry is actively exploring the use of ammonia as a marine fuel. For example, the world's largest manufacturer of marine diesel engines – MAN Energy Solutions – has an active program to develop diesel engines to safely run on ammonia. Beyond 2030 it is likely that we will see giant ships powered by clean ammonia made from clean hydrogen.

There are other applications in which clean ammonia holds great potential to contribute to a low-carbon future. It can be used to make clean fertilizer, as an industrial chemical feedstock, as an energy carrier, and as a fuel for electricity generation.

Let's, though, consider its use as an energy carrier. To export solar and wind energy from one continent to another, the sunshine and the wind energy will have to be packaged as a liquid. The two leading contenders are liquid hydrogen and liquid ammonia. The jury is out. In my opinion, both will be used. And the volumes in both cases will be huge. Between them, we are talking a trillion dollar industry by 2050.

The National Hydrogen Strategy recognises the potential for clean hydrogen and clean ammonia, and agrees that hydrogen production for clean ammonia exports should be a priority for research, pilots, trials and demonstrations. Increasing demand for hydrogen, including for use in ammonia production, could generate thousands of jobs and contribute to the growth of the economy.

> ***"Increasing demand for hydrogen, including for use in ammonia production, could generate thousands of jobs and contribute to the growth of the economy"***

Development of a certification scheme will be important for building a clean hydrogen industry and facilitating international trade. Certification will allow the emissions profile of every kilogram of hydrogen produced to be tracked. Work is underway to establish a common international methodology for certification of hydrogen production, and we are also consulting with our domestic industry on their requirements. The hydrogen certification scheme will, ideally, be applicable to the certification of clean ammonia, thereby ensuring the confidence of our trading partners.

I commend the Ammonia Energy Association for identifying the huge opportunity to use clean ammonia as the marine fuel of the future. Our planet needs visionary thinking like this. Enjoy further, far-sighted discussions at today's conference.

May the Force be with you.

CHAPTER 06

Navigating New Technologies

"What kind of society do we want to be?"

Chapter 6 | Navigating New Technologies

Introduction

Artificial intelligence can be an enormous force for good, with extraordinary advances in medicine, research, industry, security, communication and many other aspects of our daily lives. But the risks are also significant and should not be underestimated if we are to keep our privacy and individual agency, and avoid handing powerful datasets to nefarious influences.

In this series of speeches, I have called for strong regulations and a tech-savvy workforce to ensure standards stay high, human ethics remain the top consideration, and controls keep pace with technologies. Among initiatives I'd like to see are Fairtrade-style certification for ethical consumer AI, and the incorporation of artificial intelligence teaching programs with strong ethical foundations into our tertiary courses across a range of disciplines.

I am strongly of the belief that AI should not be avoided or wound back, but embraced and facilitated, with sensible solutions to ensure its safety. My office commissioned a report by the Australian Council of Learned Academies for the National Science and Technology Council on the effective and ethical development of artificial intelligence, released in July 2019. It highlights the opportunities and risks of AI, and emphasises the need for Australia and New Zealand to boost their capability in the field and ensure they are ahead of the ethical and regulatory frameworks so their decisions are not shaped by foreign governments and multinational head offices.

These speeches also speculate on the limitations of artificial intelligence, and ask, as the bots continue expanding into new territories of human endeavour, whether humans will always retain exclusivity over some skills, some aspects of the power of thought, and the subtlety of communication. Extraordinary technological advances are already bringing bionics into medicine, including for seeing and hearing, and for controlling debilitating conditions such as pain and tremors. However, the brain is unimaginably complex and its workings are well out of reach of machine replication. Perhaps they will stay that way.

30. What kind of society do we want to be?

July 24 2018 | Opening Address to the Human Rights and Technology Conference

The use of data for harm is writ large in our history. When I was telling my 96-year-old Aunty 'Rosa' about how facial recognition software is being used to monitor civilian movements in some countries, instead of awe and fascination, she went pale, and cried. My stories reminded her of hiding during World War II, as the Nazis harnessed every dataset they could find in their goal of identifying and killing Jews, using Census records, medical records and scientific studies. Technology misused to increase the efficiency of evil. It is a lesson that must not be forgotten as we welcome the great benefits of new technology and big data. This was a heartfelt moment that I used as a compelling story to open the Human Rights Commission of Australia conference on Human Rights and Digital Technology. Australia should not hesitate to formulate its own rules to delineate activity involving artificial intelligence; there is no need or reason to simply adopt the decisions of others. To this end, the Human Rights Commission is working on a template for accountable AI, and the Department of Home Affairs secretary Michael Pezzullo has articulated a golden rule that stands as a very good first principal: no robot or artificial intelligence system should ever take away someone's right, privilege or entitlement in a way that can't ultimately be linked back to an accountable human decision-maker.

A few weeks ago I took my mother and her best friend, whom I fondly call Aunty Rosa [a pseudonym], both in their 90s, to Saturday lunch. They love to hear about the state of the world and what the Chief Scientist is up to, so I decided to tell them about artificial intelligence.

First, I pulled out my iPhone and demonstrated how I can use Siri to place a phone call. Then I explained that Siri was just a plaything compared to Google's new tool, called Duplex. Duplex will place your call, perhaps to a restaurant, or a hair salon, and then speak in a natural voice to the human who answers, to make your booking. What sort of natural voice, they wondered. Any voice! I said. You could stick with one of Google's, or maybe, in the future, you could give Google your voice-print, so the voice could sound just like yours.

I told them about an email I'd received from a personal assistant named Amy Ingram. Initials: AI. Artificial intelligence. Just think, I told my Mum, right at this minute, Amy and her brother robot, Andrew Ingram, are emailing and setting up meetings on behalf of tech-savvy people all over the world. Top executives. People in research labs and hospitals and schools and maybe even government departments. Amy and Andrew have access to all their contact lists and diaries and emails! Whoa! Alan. Slow down, I said to myself. I told them that there would be consequences if Amy and Andrew were hacked to reveal financial secrets and identities … or if we passed a law requiring Amy and Andrew to spy on their employers and report anything deemed suspicious.

It's amazing, I said, how much information we're willing to give up in exchange for a bit of convenience. Think, for example, about all the photos we upload to Instagram and Facebook. All those photos can be used to train algorithms to recognise human faces.

And in China, this technology has taken off. Do you know, I told them, that facial scanning in China is used for everything from dispensing toilet paper – so you can't go back multiple times in a day – to picking out individual people in the crowd in the streets and at concerts. In some cities in China, people are assigned what's called a Social Credit Score. And you gain or lose points depending on your behaviour, including any bad behaviour caught on camera and then picked up by AI, like littering, or jaywalking. If your score gets too low, you might not get a job, or a bank loan, or permission to leave the country.

PHOTO: Nina Burridge/Twitter

And maybe, I said, we could use AI to go one step better – not just to punish the offenders, but to pre-empt the crimes. Police and security agencies in some countries are already using AI to pinpoint the people most likely to make trouble, so they can place them under closer surveillance. And welfare agencies are using algorithms to work out which children ought to be separated from their parents.

As I talked, Aunty Rosa grew tense. Tears welled in her eyes. I don't like to make my mother's friends cry, so I asked her what was the matter. But of course, I should have known. Aunty Rosa was a Holocaust survivor. For four years she lived in hiding in Lithuania, a young Jewish woman persecuted for the crime of being alive. And as I drew my little pictures of the future, she saw only the brutal truth of the past. A life lived in fear of being watched. By neighbours. By shopkeepers. By bogus friends. And to this day, her fear was so overwhelming that she would not consent to let me use her real name, in sharing something of her story with you today.

She didn't know at the time, and I'm not sure if she would want to know now, but it was data that made a crime on the scale of the Holocaust possible. Every conceivable dataset was turned to the service of the Nazis and their cronies. Census records. Medical records. To the eternal shame of scientists, even the data from scientific studies.

With a lot of data, you need a sorting technology. And the Nazis had one. Not computers, but their predecessor – tabulating machines using punch cards. Little pieces of stiff paper, with perforations in the rows and columns, marking individual characteristics like gender, age and religion. And that same punch card technology that so neatly sorted humans into categories was also used to schedule the trains to the death camps.

So Aunty Rosa suffered from data, plus technology, in the hands of ruthless oppressors. But she survived the war and she came to Australia. And here she found a society where people trusted in government, and in each other. She saw the same technologies that had wrought such terrible crimes in eastern Europe used here for the collective good.

Yes, data in a humane society could be used to help people – to plan cities and run hospitals and enrol every child in school. You could get a driver's licence without fear. You could carry a Medicare card, and feel grateful. You could live quietly in your own house, free from surveillance and safe. People weren't perfect. But for the most part they lived peacefully together, in a society governed by manners and laws, using technology to make life better.

> ***"Artificial intelligence could surely be put to the service of human rights"***

And in that kind of society, artificial intelligence could surely be put to the service of human rights. I think of the right to ease of travel. What might self-driving cars mean for the elderly, or people living with disability? I think of the right to freedom from slavery and forced labour. Border-security agencies are using AI to find the victims of human trafficking. They can collect the images of women reported missing, and compare them to the faces of women crossing national borders, or appearing in any of the millions of advertisements posted online.

I think of the right to found a family. Researchers based here in Sydney are using AI to improve the outcomes of IVF. In the standard procedure, embryos are assessed by the doctors to choose which ones to implant to maximise the likelihood of a successful pregnancy. AI can make that choice far more swiftly and reliably. So we can spare families at least some of the trauma and expense of IVF cycles that fail. A caring society could not possibly turn its back on all that potential. I know that my mother and Aunty Rosa would agree.

As I told them about the power of AI, they wanted only to know that a future Australia would still be the place they had grown to cherish. Where you could be happy and safe and free. "How," Aunty Rosa asked, "will you protect me, my daughter and my granddaughter from living in a world in which we are constantly monitored? How, dear Alan, will you protect our liberty?" Aunty Rosa's question to me is, in my words, my challenge to you. What kind of society do we want to be?

I look around the world, and it seems to me that every country is pursuing AI its own way. It's true. There are some questions that we can only resolve at the level of global agreements, like the use of AI in weapons of war. But the way that we integrate AI into our societies will be determined by the choices we make at home.

Governments decide how companies are allowed to use data. Governments decide how to invest public funds in AI development. Governments decide how they want to harness AI, for policing and healthcare and education and social security – systems that touch us all. And that means nations like Australia have choices.

We are capable technology innovators, but we have always imported more technology than we develop. That's inevitable, given our size. However, that doesn't mean we have to accept the future we're handed by companies in China, or Europe, or the United States. To the contrary, we can define our own future by being leaders in the field of ethics and human rights. And that is my aspiration for Australia. To be human custodians.

In my mind, that means showing the world how an open society, a liberal democracy and a fair-minded people can build artificial intelligence into a better way of living. Am I asking too much? Perhaps. But let's not forget we've been pioneers of progress with ethics before.

I've been reflecting this week on IVF. Tomorrow, the world's first IVF baby, Louise Brown, will celebrate her 40th birthday. It's fascinating now to look back at all the things that were written and said when she arrived. People thought that it was unnatural. That the babies would be deformed or somehow less than fully human. Or that we would start making humans in batch lots, in factories.

But here in Australia we listened to the patients and the clinicians who saw the real promise of this technology. No-one could hand us a ready-made rule book. There wasn't one. So we had to create one. And we did. We were the first country to collate and report on birth outcomes through IVF. We built a regulatory model that kept our clinics at the leading edge of the science, whilst keeping their patients safe. We published the first national ethical guidelines on IVF, anywhere in the world. We harnessed the Medicare system to help families to meet the costs – and clinics worked closely together, so that success rates improved steadily, right across the country. And so IVF became a mainstream procedure, getting better over time.

There are lessons here for the approach we take to AI. The first and most important: don't expect a single answer or a one-shot, set-and-forget AI law. That wasn't the secret to adopting IVF. No, we had a spectrum of approaches that worked together and evolved in line with the state of the technology, and the levels of comfort in the community. There were laws and regulations, there were industry codes and practices, and there were social norms. We will need to develop a similar spectrum of responses to AI, so that we can strike the balance between opportunity and risk.

I've been thinking in particular about the low-risk end of the spectrum. By this, I mean products like smartphone apps and digital home assistants that promise to make your life a bit easier. What if we had a recognised mark for ethical technology vendors – like the Fairtrade stamp for ethical suppliers? In my mind, it's called the Turing Certificate.

The standards would be developed by a designated expert body, in close consultation with consumer groups and industry. Then companies that wanted to display the mark would submit both the specific product and their company processes for an ethics audit by an independent auditor. So you as a consumer could put your purchasing power behind ethical developers – and developers would know what they need to do to make the ethical products that people want. This could be an idea that Australia could pilot and help to spread. But I emphasise, this voluntary system would be suitable only for low-risk consumer technologies.

What about technologies that touch more directly on our freedom and safety? Where else could Australia be influential? I point you to the public sector. We have a cohort of leaders right across government squaring up to their responsibilities as AI adopters and human custodians.

Just last week, the secretary of the Department of Home Affairs, Michael Pezzullo, went on the record with his agency's approach to AI. And he went further, proposing a line in the sand not just for border security but for every decision made in government that touches on a person's fundamental rights. He called it the golden rule: No robot or artificial intelligence system should ever take away someone's right, privilege or entitlement in a way that can't ultimately be linked back to an accountable human decision-maker.

> ***"No robot or artificial intelligence system should ever take away someone's right, privilege or entitlement in a way that can't ultimately be linked back to an accountable human decision-maker"***

To me, this golden rule is a partial answer to my question. It is the mark of a public sector fit to be an ethical custodian. And I know, from my conversations with leaders in many agencies, that they are looking to the Australian Human Rights Commission to help them interpret that custodianship.

Today we are launching a three-year process to consider these issues. To identify the manners, ethics and protections that will work for all of us, not just the early adopters. I applaud the initiative of Human Rights Commissioner Ed Santow and his colleagues. We must all be involved in this national discussion. And every time we come to a decision point about the technologies we allow into our lives we must ask ourselves, what kind of society do we want to be? To start, let's be a society that never forgets to ask that question.

31. What Manufacturing can Teach AI

May 14 2019 | Opening Address at National Manufacturing Week

Manufacturing is in my blood. My father established and ran a large textile factory in Melbourne, and while I did all the obvious things to strike out on my own – a university degree that he was denied, a PhD that he could have never contemplated and then a postdoctoral fellowship for further certainty – like a moth to a flame, I was drawn to manufacturing. I went to Silicon Valley, California, and established a company to manufacture sophisticated electronic research equipment for neuroscientists. And over the years I learned about quality assurance. And safety. And meeting and beating the regulatory requirements. Good luck selling an electronic device that does not meet all the applicable regulations and display the applicable certifications. If something goes wrong, penury, jail, or both will ensue. But AI is mushy, not as obviously dangerous as electricity, and to a large extent it is unregulated. AI is seeping into every aspect of our lives, from sharetrading and mining, to cars, the media, medicine and security. Facial recognition technology is ubiquitous and the phones in our pockets are becoming phenomenally powerful data hubs, with all of the potential for perverse outcomes, privacy breaches and loss of liberty that you can imagine. As countries scramble to develop sets of ethical principles to guide and regulate this industry, I have been promoting what I'm calling a Turing Certificate for AI, a Fairtrade-style certification, so when we buy a device or download an app we can be assured that it passes tests of ethics and privacy. It is a small step, but sorely needed.

As Australia's Chief Scientist, I go to a lot of industry conferences. I think I've spotted a general trend, and I'm sure it applies to manufacturing. Up on stage, there are any number of people who don't work in a given industry who think they know exactly what people who do work in that industry ought to do. And I'm certain there are any number of people who've never set foot in a factory who want to tell manufacturers exactly what they ought to do about artificial intelligence – AI.

Now I agree that talking about AI is important, and ignoring all those people would be a terrible mistake. But today I want to flip the script. And instead of talking about what manufacturing needs to learn about AI, I want to talk about what AI development needs to learn from manufacturing. And I want to encourage all of you here today to reflect on how the systems we've developed to ensure quality and safety in manufacturing can help us achieve a world of responsible AI.

> ***"The systems we've developed to ensure quality and safety in manufacturing can help us achieve a world of responsible AI"***

But let me begin by laying out my credentials. I come from a manufacturing family. My father, David Finkel, was a maker of women's clothing. He was born in an industrial town in Poland, called Bialystok, famous then and now for making two things, vodka and carpets.

If Dad had stayed in Poland he might have followed the path my grandfather had planned for him – starting a rug-making business in another part of the country. But this plan was shattered by the German invasion and Dad was forced to seek refuge in Siberia instead. Then, as soon as he could after the end of the War, Dad got on a boat, and he came to Australia – with nothing.

Or nothing, at least, in his pockets. He had courage and initiative in spades. He also knew factories – he'd known them all his life – and he knew that manufacturing is how migrants who start with nothing can get ahead. So that's exactly what he did. He built a clothing business in Melbourne that at its height employed over 400 workers. And he gave many people – migrants, just like him – their start.

I admired my father and his business acumen enormously. But I never expected to follow him into manufacturing. When I left school, my plan was to study engineering. I got my degree and I started my PhD on – wait for it – the electrical activity in the brains of snails.

It turns out to be extremely difficult to study the basics of what goes on in brains, even little snail brains. I became obsessed with the need for better tools. And eventually I came up with a design for a new kind of electronic amplifier called a voltage clamp – which you don't need to know anything about, except for the fact that it overcame a big limitation in all the existing designs. People started asking me where they could buy my electronic amplifiers. I realised that in order for people to buy them, I'd have to make them.

So that's what I decided to do. In 1983, at the age of 30, I said goodbye to my research career at the Australian National University and I went with my wife to Silicon Valley. A migrant, without suppliers, without customers, without a workspace. Everything I had was basically in my head. I set up a company called Axon Instruments, and I went into manufacturing just like my father. Head-first.

Axon was a one-man company, and the one man was me, which made it very easy to get unanimous agreement on a wages policy but very hard going in every other respect. But I survived that first nerve-shattering year, and so did Axon. I got that electronic amplifier on to the market, and we actually turned a profit, even though my parts alone cost as much as the retail price of my nearest competitor. To cover direct and indirect labour and other overheads I would have to charge twice as much as the competition. I was a novice in business, but it occurred to me that this might be a problem. I made a panicked phone call back to Australia, and it was my step-father who picked up the phone. "Alan" he said to me, "is your product truly better than the competition?" "Absolutely," I said. "Then charge what you need to charge, because quality is remembered, long after price is forgotten." That was manufacturing 101.

But then, manufacturing 201: you're only as good as your most recent product. So for the next two decades I worked constantly, in my company, for my company and on my company, making new products and then making them better. Any of you here today who have built a thriving manufacturing business and kept it going, you have my respect.

By 2004, we employed close to 150 people, the company was still expanding, and I decided the time had come to move on. I sold the company, agreed to stick around for 18 months as the Chief Technology Officer of the acquiring company, and then woke up on January 1st, 2006, a free agent.

I tried retirement, but it was awful. So I went back to work, and I ended up as the Australian public's on-call science adviser and in-house engineer.

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Looking back, I can match the phases of that story against the bigger trajectory of history. My father's factory. That was Industry 2.0 at its height, the golden age of capitalism, when the population was growing and so was the economy, building on the massive technology dividend from the Second Word War.

My company, Axon Instruments, that was Industry 3.0, the computer age. I founded Axon when IBM was rolling out the very first personal computer. It was one of my first big investments: $US10,000, with, by today's standards, a miniscule 10 megabyte hard drive and just 384 kilobytes of memory. That's about $37,000 in Australian dollars today.

20 years of Axon Instruments
PHOTO: Alan Finkel

I sold the company 21 years later, just as Apple was getting ready to launch the iPhone. So yes, in my time as a CEO, Industry 3.0, I saw every aspect of manufacturing transformed.

And now, your factories today: Industry 4.0, the era when artificial intelligence is ascendant, coupled with rapidly accelerating progress in the Internet of Things, additive manufacturing, nanotechnology, biotechnology, materials science, energy storage, digitalisation and embedded computing.

Why do we say that we're entering a different era, with AI at its core? Well, geologists say we can mark off a new epoch in world history if we see a universal signal – meaning it registers all over the globe – and it shows up as a distinct shift when we look back through the layers of rocks.

By analogy, we enter a new industrial era if we have a force that becomes ubiquitous, that registers in the economic indicators. To be fair, we haven't seen a definite AI productivity spike. But we wouldn't expect to, because we're in the learning phase, when the experiments are risky, and often, they don't go right.

PHOTO: Office of the Chief Scientist

For example, the world-famous "Fluffbot". Fluffbot was a robot developed for Tesla's gigafactory in Nevada. He had one job, to put fibreglass insulation fluff around the battery pack. Piece of cake for a human. Seriously advanced for a machine. And Fluffbot literally fluffed it. He couldn't pick up the fibreglass reliably. And when he did pick up the fibreglass, he couldn't find the battery. So he'd just drop it somewhere else. Tesla concluded that he wasn't helping, and retired him.

The media loves these stories, but it would be wrong to see the failures and miss the trend. Remember, it took us decades – decades – to see the productivity gains from developments we now understand to be transformative, such as electricity and IT.

And the trajectory in AI is clear. The individual efforts are becoming bigger and bolder – and collectively, they're surging into a wave. Already, today, AI routes trucks. AI makes more share trades than humans. AI chooses the news. AI writes the news. In China, an AI even presents the news. On TV. AI is in security cameras, an estimated one billion of them globally by next year. AI is in our phones, four billion of them already equipped with AI assistants. AI drives cars. But who's impressed by cars? Think trucks. In Australia, AI drives dump trucks on mine sites, trucks the size of two-storey houses. And AI drives the trains to the port. On the other side of the country, at the Port of Brisbane, giant AI straddle-carriers stack and load the cargo. And, of course, AI is seeping into every aspect of manufacturing – and manufacturing companies are buying up AI talent as fast as universities can churn it out.

Ten years ago, we'd argue about the big and abstract threat of a robot apocalypse. Today, we're grappling with the real and present impacts of AI on our businesses, our jobs and our children. In short, our society. Do we want to live in a world where employees can be constantly monitored, and the least productive workers are automatically sacked? Who should be reading our job applications and mortgage paperwork and medical scans, humans or machines? When is an automated driving system or production line sufficiently safe to be worthy of trust? And how do you transition decision-making responsibility to that system over time, whilst keeping the human operators alert and engaged?

All of these questions are complicated by the massive information gap between the people who develop AI and the people who deploy it – and the bigger gap again to the people whose lives it affects. As consumers, we don't see the algorithms at work in our newsfeeds, or know if our job applications will be read in the first instance by a human or a machine. And even when we do see AI in a physical form – like the SmartGates at airports that use facial recognition to verify identity – many people don't make the connection that this is AI at work.

We're still trying to find our way through an increasingly angry debate. On the one hand, there are people who insist that AI needs to be banned, smashing the glass and pulling the emergency brake on the train of progress. On the other hand, there are people who insist that any attempt at government control of AI is premature, that technological development and the wonders that it delivers blossom best in an unregulated free for all. On the first path, people with scruples give up on building AI with ethics. On the second path, we say that scruples and ethics don't count. Either way, the unscrupulous win.

But I look at the long history of manufacturers bringing new technologies into our lives. And I think of technologies that are inherently dangerous, like electricity and cars, that we have accepted in our lives for decades. And I also think of technologies such as medicines, and how we have learned to minimise the adverse side effects associated with their tremendous power to heal. We trust in our capacity to manage these technologies, not to ban them.

When you think about it, about all the things that have to go right, every time, for a safe and effective product to arrive in our hands, at a price we can afford, at the moment we want – in a country like ours where doing business isn't cheap – that level of confidence is extraordinary. It didn't exist at the dawn of Industry 2.0, and it still doesn't exist in many places around the world today. Quality is the Australian brand. Quality assurance is an Australian strength. That says to me that there's an incredible repository of knowledge and experience in manufacturing. Right here. And there's a lot to carry forward with AI.

> ***“Quality is the Australian brand, quality assurance is an Australian strength”***

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Let's think about how quality assurance works in manufacturing. As a manufacturer, you understand that your practices are guided by a mesh of interlocking systems, all designed to strike the optimal balance between quality, speed and safety.

At one end of the spectrum is legislation – hard requirements, with criminal and civil penalties. Then there are industry codes and standards, sometimes binding, sometimes voluntary, but you adhere to them because that's what your peers and your customers expect. Next on the spectrum are the practices that you adopt internally – feedback loops to your customers, data gathering, project evaluations, employee training. And finally, there are measures designed to inform consumers about what products do and how they are made, so that they can give their dollars to the companies that line up best with their values.

When you first go into business, you think these things are constraining. In time, you realise that good regulation is a CEO's best friend. It's the way you get permission from the community to be in the game. Once you know the rules, and you know you comply with them, you can get the backing from investors and play to win. It means it's good business to do the right thing.

That's what we should develop around AI, not one law of AI, but a spectrum of approaches – legal, financial, and cultural – all working together. I've been thinking in particular about the consumer end of the spectrum. If you're in the market for an AI baby monitor, or you're a business thinking about installing AI security cameras in your warehouse, how do you know if the product and the company that created it are trustworthy? You could read the 100-page disclaimer, but you won't. Maybe if you're a government department with a big procurement budget, you can put more resources into due diligence.

But what, exactly, are you trying to find out? How do you know if the AI has been trained on a quality dataset? How, for example, would you know that an AI used for targeting job ads to the best candidates isn't biased? How can you be confident that the system you installed last week will still be properly supported in two years' time? And even if you do have your own idea of good practice, how do the AI developers come to understand your expectations?

I was turning this problem over in my mind. And I thought about the efforts that Australian industry has made in recent years to clean up the supply chain in partnerships with many activists in the community. A consumer can't tell if a T-shirt has been produced with slave labour, or if the grower of their coffee beans was paid a fair price. But they can look for the Fairtrade mark, which tells them that the product complies with a certain minimum standard.

Then I thought about my own experience many years ago, taking my company along the journey to becoming ISO 9000 certified. We needed ISO 9000 certification in order to be able to market a new product that inserted an electrode 10 centimetres deep into human brains, during neurosurgery to treat the symptoms of Parkinson's disease. As we discovered, the beauty of the ISO standards is that they give you a process for achieving quality by design, not by testing and rejecting. They force you to bake high expectations into your business practices, and they keep you honest by a combination of internal and external audits. At Axon, we maintained these exacting design and business practices for our non-medical products too, because they made us a better company and gave us a commercial edge.

So imagine if we could do the same with AI: develop a standard and certification system for quality, safety and ethics. In the past, I've outlined one possible model for consumer products such as digital assistants, which I've called the Turing Certificate, in honour of the legendary Alan Turing.

But mine is just one of many ideas in this area. I've just come back from the United States where I met with the chief scientific advisor to the President, Kelvin Droegemeier. His office is taking the lead on an executive order signed by the President in February. It commits the federal government to leadership on AI governance in its own practice, and in the standards it applies to others. That includes the development of technical standards for reliable, robust, trustworthy, secure, portable and interoperable AI systems, in consultation with industry – a process now underway. The message is clear: America wants a rule book, and they want Americans to write it.

Over in Europe, the European Commission has just kicked off a large-scale pilot of its Ethics Guidelines for Trustworthy AI. It's a set of seven principles, supported by a list of practical questions that you as a CEO need to consider, whether you're a developer or a purchaser. For example, did you put in place ways to measure whether your system is making an unacceptable amount of inaccurate predictions? How are you verifying that your datasets have not been compromised or hacked? The idea of the pilot is to test the set of questions, to ensure that the guidelines can actually be embedded in practice.

Here in Australia, CSIRO's Data61 is now consulting on our own AI Ethics Framework, commissioned by the Government in last year's federal budget. The discussion paper is out there; you've got until the end of this month to make a submission. And there will be other calls for your input, on multiple frameworks, as we get down to work on that spectrum of rules.

So why should Australian manufacturers pay attention? First, because it's very much in your interests to opt in. Imagine if consumers who currently think of all things AI as an impenetrable fog had some capacity to distinguish between the good and the bad. How much easier would it be to win support for the AI tools you want to adopt, if you could point to a rigorous external standard? In particular, how much easier would it be to do business with big customers who will be willing to pay a premium for quality, such as governments? We know that Australian manufacturers compete on quality, safety and ethics, so let's get behind a scheme that makes those qualities count.

And second, if it's in your interests to opt in, then it's also in your interests to get involved in the standards development process, today. You've got the experience with quality assurance approaches that work. You know that we're strengthened by good regulation. You can bring your perspective to best practice requirements for AI.

* * *

It's still going to be a decade of tricky decisions. And everyone here will be making them. Am I glad that I'm a failed retiree turned public servant these days, instead of a CEO? You bet. It's nice not to be responsible every minute for the future of the company and its employees.

But even to this day my analysis and advice is informed by my experience as a manufacturer. The reality is that we know more than we think we know. So, from one proud son of a manufacturing family, to the manufacturing family here today, enjoy the conference.

And, in the closing salutation of my generation, may the Force be with you.

32. AI on my Device, not in the Cloud

April 29 2020 | Video Address for the launch of the University of Melbourne's Centre for Artificial Intelligence and Digital Ethics

The ultimate artificial intelligence problem is how to reap all the benefits without giving up privacy and being bombarded by coercive advertising, or worse. Once again, it is science fiction that provides the answer. The answer is both surprisingly obvious and currently out of reach. Put simply, the answer is more technology. As much power in my smartphone as the computer on the starship Enterprise in the first (and best) Star Trek television series. So much power in my smartphone that it will not need to reach out for help to the corporate master computers that do the heavy thinking today. More technology, not less. The more we can bring the backroom smarts of AI out of the cloud and into our homes and phones, the closer we can guard our information.

Let me start with a pop quiz. Who said the following: "Computers make excellent and efficient servants, but I have no wish to serve under them"? Was it Alan Turing, the father of computer science and artificial intelligence? No. Surely then it was author Isaac Asimov, who devised the Three Laws of Robotics designed to prevent robots harming humans? No. It was none other than Mr Spock, the half-Vulcan, half-human Science Officer and second in command of the Starship Enterprise.

You may recall that the Enterprise's mission of exploration and intergalactic diplomacy was ably supported by an assortment of high-tech gadgets. Phasers, tractor beams, tricorders and an on-board computer capable of performing, within the confines of the ship, all the processing that was necessary to answer the Enterprise's queries. The crew of the Enterprise weren't at all concerned with sharing personal and military secrets with the computer, and they certainly didn't get bombarded with endless advertisements. That was the magic of the Enterprise computer – all of its processing was localised. And herein lies the technological gulf between those on board the Enterprise, in the future, and us residing on this planet, in the present.

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When I use my iPhone, and I use Siri a lot, I press the button and say "Siri, call my wife, Elizabeth Finkel". And Siri very happily replies "calling Elizabeth Finkel". And it works really well, unless of course I am in an underground car park. In that case, Siri goes silent for five seconds, 10 seconds, before sheepishly saying "uh oh, I'm having trouble connecting".

What this tells me is that the speech processing is not being performed on my iPhone. Instead, it takes place, on an unbelievably fast server, thousands of kilometres away. My instruction goes by optical fibre to a server, a gigantic, powerful computer in the United States, in about 50 milliseconds. The server processes my words and sends them back to my phone as digital instructions rather than the original audio.

Nearly everything smart you do on your phone is actually handled by servers; that means all the information about what you are doing is stored, deconstructed and analysed by servers devoid of any morals. They are servers not servants, and, as such, they present an ethical dilemma.

I, of course, want the immense benefits that AI provides. But I am alarmed that, in order to do so, my smart device relies on the AI in the cloud. From the cloud, companies can identify me, follow me around, send me advertisements and potentially share my information with third-party organisations.

"In this new age of artificial intelligence, our key challenge is to harness the power of science to enhance human lives without sanctioning practices that violate human dignity"

In this new age of artificial intelligence, our key challenge is to harness the power of science to enhance human lives without sanctioning practices that violate human dignity. It is my hope, therefore, that CAIDE, the Centre for Artificial Intelligence and Digital Ethics, in joint collaboration between the faculties, will have a two-pronged approach in guiding the development of AI and digital ethics, one short term and one long term.

* * *

In the short term, with servers being the unavoidable foundation of today's AI, we must always remember this basic truth: no matter how fast the pace of AI innovation, it must never surpass the primacy of human rights. For innovation divorced from values, a head without a heart, can only serve to harm humanity.

Totalitarian states offer a cautionary tale of what can happen when technology is turned into a tool for tyranny. My belief that AI must serve the individual, and not the other way around, is rooted in my own story. I stand here today as someone whose life was made possible by the promise of our ideals, and the protection of our laws.

My father came to these shores in search of that promise and protection. He was born in Bialystok, in northeastern Poland, and as a young man had been sent by his father to the southern part of the country to establish a rug-making business. But the Second World War interrupted this venture. Being Jewish, Dad's family suffered Nazi persecution that, for the first time in history, was facilitated by data and technology.

Punch cards with census information and tabulating machines able to sort 25,000 cards per hour were repurposed by the Nazis to target individuals deemed undesirable by the regime. Many of Dad's relatives were systematically identified and executed for the crime of being alive. Of course, the Nazis had the pretence of justice. They had courts. They had a constitution. But these were designed to serve as a cynical veneer for murder and oppression. The rule of law twisted and degraded into a perversion of law. Dad spent most of the war in Siberia, before he and his brother made it here on the first ship to bring out Jewish Holocaust survivors.

PHOTO: Office of the Chief Scientist

When he arrived in Australia, he found that the strength of the state rested on the strength of our democracy. He found citizens free from fear, who held their leaders accountable through open and honest elections. He found the same technologies that had wrought such terrible crimes in Europe used here for the collective good. And an independent judiciary dedicated to defending the liberty and equality of all. And that promise has only grown over time.

We must always remember that the same enlightened society that advanced the cause of science has also advanced the cause of justice. The same persistence that opened up new frontiers of discovery also opened new doors of equal opportunity. As the holders of this legacy, we bear great responsibility to ensure these sacred ideals continue to be afforded to everyone.

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Indeed, this spirit of achievement and special responsibility has defined the University of Melbourne, in particular, ever since its foundation stone was laid in 1853. It is that spirit that has made this institution a central part of Australia's intellectual heritage and a central part of our larger national story.

This institution has been the home of many firsts – the first university established in Victoria; the first woman to graduate from an Australian university. But key to its mission has been to ensure those firsts led to more breakthroughs. Progress has been this institution's hallmark. Generations of dreamers and innovators have come to these halls determined to strive for more. Armed with a willingness to question conventional wisdom and change the way we see the world.

None more so than Professor Graeme Clark, inventor of the Bionic Ear. As Professor Clark once noted, all the scientists around the world said it wasn't possible. But it was possible.

And now, emerging researchers, it's your turn. You have doors open to you never before afforded to any people in any age. You can help foster a society where our enduring ideals and our technological aspirations are both furthered and strengthened.

By design, CAIDE will not be a silo. It will work on incorporating AI into all fields of study, thereby becoming a connective tissue across the university. By conducting interdisciplinary research and teaching, supporting emerging researchers, and collaborating with national and international industry and university partners, CAIDE can foster a cross-pollination of ideas that will lead to advances of unlimited potential. And this, I believe, is exactly what will be required in the future to ensure we can pursue the tremendous possibilities of AI while still fulfilling our moral duties.

In the long term, I believe that the way forward for AI is more technology. I want us to boldly go where no one has gone before and make the computer on our phones so powerful that there is simply no need to risk our privacy or security. I want the power of the Star Trek computer on my phone, with all the processing nous and capability to take my complex questions, interpret them without ever seeking advice from a server, and then anonymously reach out to the cloud to get the answers I need. AI on my device, not in the cloud.

And please don't tell me this ambition is highly illogical. In fact, I know we have the capacity to make it so. In November last year, I attended a government summit called Techtonic, hosted by the Minister for Industry, Science and Technology, Karen Andrews. Techtonic explored opportunities to maximise the benefits of AI for Australia.

It was there I first learned about Home Guardian, an Australian company with a very simple system that has the potential to revolutionise the aged care, disability and hospital sectors. Using a world-first artificial intelligence device, Home Guardian uses sensors to monitor movement. Its single-minded job is to alert carers or family members if an unexplained fall occurs. The AI inside Home Guardian is trained in advance. Without even being connected to the internet, it knows how to identify objects in a room, what normal behaviour and interaction is, and most importantly, what isn't normal. Once abnormal interaction or behaviour is detected, it alerts a loved one, carer or nurse via text message, all without compromising the user's privacy.

Because no images are sent outside the user's home and no internet is required, Home Guardian is able to do its job without ever needing to consult an external server. Without ever needing to risk your privacy.

Imagine for a moment downloading an app for your smartphone or digital home assistant designed for a similar purpose. An app that, unbeknownst to you, has been compromised, allowing cybercriminals to spy on you and determine when your home is empty. I'm afraid such a frightening prospect is coming closer to reality.

Last year, German researchers were able to create four apps for Amazon Alexa and four for Google Home, all of which passed the security vetting processes of both companies. On the surface, these apps were simple horoscope applications. In reality, they were smart spies that had the capacity to allow the researchers to spy on users and phish for their passwords. At a time when artificial intelligence has some relevance to all, this revelation is disquieting for all.

For AI's future to be assured, it must be seen by the public as an effective and safe instrument for individual empowerment, and not as an instrument vulnerable to exploitation. I want my future AI phone being my servant, not somebody else's.

> ***"For AI's future to be assured, it must be seen by the public as an effective and safe instrument for individual empowerment"***

As such, last year the Australian Government released a set of AI Ethics Principles to build public trust, as well as help guide businesses and government to responsibly develop and use AI systems. But these principles require that we take the actions that will give them meaning and purpose.

Our rights, our freedoms, are not a given. They must be jealously protected and constantly renewed to meet the challenges of our time. The work you will do here, therefore, will have a profound influence on our homes, on our communities and ultimately on our nation. It will have a ripple effect on our daily lives, the lives of our children and the kind of Australia they will inherit tomorrow. I congratulate everyone who has worked tirelessly to make this wonderful vision a reality.

May CAIDE strengthen our nation's sense of purpose and ambition. May it live long and prosper.

33. Harnessing the Power of Artificial Intelligence to Benefit All

October 31 2019 | Speech at the Go8 Artificial Intelligence Collaboration and Commercialisation Summit

Oh dear. I wrote an article once that said it would be a long time before AI would recognise faces as well as humans could. Wrong. Artificial intelligence is now more accurate than humans. I used to think that art and music would be beyond the reach of AI in my lifetime. Wrong. Artificial intelligence can now paint in the style of Rembrandt and compose in the style of Mozart. I used to think that it would be too much to expect AI to mimic a human voice and have a friendly chat. Wrong again. The boundaries between humans and AI are overlapping, so how will we understand our own role? No idea, but I am sure that by thinking about the questions in advance we will do better than by thinking about them late. I am not alone in wanting AI to be the servant of humanity. In the United States, MIT university has set up a new college dedicated to teaching "bilinguals" – students fluent in modern computing alongside their other fields of chemistry, politics and history. I urge Australia to follow this example and teach the skills required to design and use AI as part of university courses in all disciplines. It is crucial that we develop not only the technical skills, but also a sophisticated ethical and legal framework to ensure we keep human rights and privacy at the core. Humans are not servants. Nor are we datasets to be mined.

In 1770, a Hungarian inventor named Wolfgang von Kempelen unveiled his latest creation to the Imperial Court in Vienna. Was it an animated carnival mask? A gravity-fed water purifying machine? No. It was a chess playing machine that beat its human opponents with confident ease.

Dubbed "the Turk", the machine consisted of a life-sized, human-like figure, dressed in robes and a turban, seated at a wooden cabinet that was overlaid with a chessboard.

Von Kempelen made a great show of displaying the machine's inner workings. He would open the cabinet doors to reveal a whirling clockwork of densely packed wheels, cogs and levers. The Turk would then be wound up and, as described by Edgar Allan Poe, begin to "roll its eyes, as if surveying the board, move its head, and pronounce the word "check" when necessary", and the phrase "checkmate" with glee. The automaton became a global sensation, drawing huge crowds at exhibitions, and defeating human challengers such as Benjamin Franklin, Napoleon Bonaparte, Frederick the Great and the Emperor and Empress of Russia. The age of artificial intelligence had apparently begun.

But, alas, the Turk turned out to be a hoax. A sequential roster of human chess masters would hide inside the cabinet, controlling the Turk's movement through a clever arrangement of magnets and strings to make it appear as if the machine was outsmarting humans.

Fast forward to 2005, when Amazon borrowed the concept with the launch of the Amazon Mechanical Turk – an online marketplace where, like the chess masters of the 18th century, people, hidden from view, can be hired by companies to perform discrete tasks that computers are currently unable to do, such as identifying specific content in a video. As they go about their tasks, the actions and decisions of these online workers are providing the world's biggest tech companies with high-quality data that is then used to train computer systems to better recognise patterns, creating ever-more accurate algorithms, until, eventually, there will no longer be a need for human intelligence – eliminated, one microtask at a time.

As AI becomes more and more powerful, I find myself looking for areas where we mere mortals, otherwise known as humans, have the upper hand. It's a diminishing pool.

"As AI becomes more and more powerful, I find myself looking for areas where we mere mortals, otherwise known as humans, have the upper hand. It's a diminishing pool"

It took more than 200 years after the Turk, but in 1997 IBM created Deep Blue, the first supercomputer to defeat a reigning world chess champion – without the hidden human. But at the time we humans could take solace, because Deep Blue relied on brute force to achieve victory, rather than analysing gameplay and visualising the possible moves. Surely, I thought, we humans would have the upper hand in poker, a game requiring human intuition and bluffing. Most commentators believed it would, therefore, be a holdout. But that border was breached in 2017.

Then surely human intelligence would have the upper hand in the Chinese game of Go, which has trillions more potential moves than chess. Another breach, this time in 2016, when a program named AlphaGo, developed by UK company DeepMind, beat the world's best player. This was truly artificial intelligence, where AlphaGo learned from hundreds of thousands of games played between humans until, ultimately, it worked out how to master the game. Then, to add insult to injury, a year later an improved version was produced – AlphaZero. So smart that it didn't even bother to look at human games. Instead, AlphaZero was simply given the rules, then played hundreds of thousands of games against itself, starting as a complete novice but getting better and better every second. Thirty-six hours after it was switched on, AlphaZero defeated its predecessor and became the Go world champion.

For many years I thought that recognising faces would be the mark of our superiority. In fact, like other pundits, I used to explain to anyone who would listen why it would be so difficult for AI to beat us on facial recognition. But sure enough, while I was still expressing my confidence in our superiority, the threshold was reached where AI could recognise faces more effectively than we humans.

PHOTO: Group of Eight

So what is the next human capability that is uniquely ours and beyond the reach of AI? Is it art? Not really, there are programs that paint original paintings in the style of Rembrandt. I know, I said to myself, it has to be speech writing. So I did a Google search and found that, so far, it's not happening. So I put it to you that this is the next frontier. We can be proud to be human because we remain solely capable of stringing thoughts together for a speech. And it is our thoughts, our unique human ability to meditate on the known and unknown, that will be critical as we delve into the challenge of ensuring that our zeal for innovation never betrays our values.

Science often moves faster than our ability to fully grasp all of its implications, leaving a trail of moral and ethical dilemmas in its wake. As the genius of AI pushes the boundaries of what we can do, we are faced with increasingly complex questions about what we should do. Answering these questions requires the application of ethics rather than physics. As such, it is not the province solely of scientists, but of every individual.

That is why today's summit is so important. Each of us here is not simply sharing in a one-off event. We are sharing in an ongoing effort to harness the power of scientific progress for the benefit of our society, while safeguarding the ideals of our society. The thoughts exchanged here today will go a long way to ensure that AI is the servant of our needs instead of the other way around.

So let me share with you some of my thoughts. I believe we must pursue the tremendous possibilities of AI, and I believe we can do so while still fostering our commitment to human values, to the good of society, and to our basic sense of right and wrong. My belief stems from the fundamental tenets and ideals of Australia itself. It is shaped by our history, by our proven capacity to adapt to rapid changes and by the egalitarian nature of our society.

There is a question often put to me: is Australia likely to be a leader in developing AI or just a follower who imports AI? I believe this to be a false dichotomy. We are capable technology innovators, but we have always imported more technology than we develop. That's inevitable, given our size. However, that does not mean we have to accept a future dictated by overseas companies. To the contrary. With smart, strategic applications we can find niches where we can excel and define our own future.

Indeed, the latest Australian Research Council review of university research performance found 11 of our universities are currently performing at world standard in the field of artificial intelligence, 11 above world standard, and seven out of 40 well above world standard, up from only one university at that ranking in 2015. This is a wonderful achievement, and testament to the strength and capacity of our university system.

But when stated by themselves, statistics can detract from the human element behind the numbers, the promise of what this can mean for people's lives. I firmly believe that the unmatched opportunities for AI will only be assured in this country if it is developed with an eye to demonstrating clear benefits to individual Australians. Focusing on what CSIRO Chief Executive Officer Dr Larry Marshall calls AI for a purpose.

Through this lens, I am personally interested in looking at fields as specific as AI for medical diagnostics, AI for agriculture and AI for financial services. Which is why, as Australia's Chief Scientist, I am currently managing work of the National Science and Technology Council on AI for Manufacturing. In a field that has always been at the forefront of progress. There is enormous potential for AI to shape the future of manufacturing, both the scope of what manufacturers can create and how they create it. But for AI's opportunities to be fully realised, Australian businesses and their workers will need to be adequately prepared and equipped to embrace its benefits.

> ***"For AI's opportunities to be fully realised, Australian businesses and their workers will need to be adequately prepared and equipped to embrace its benefits"***

And so, we look to you, our researchers and academics – the experts in AI development, implementation and adoption – to cultivate the necessary skillsets. Across the breadth of our universities and ultimately across the breadth of our society. This important role of universities was very prominent last month, when MIT in the United States launched a brand new college for AI. The goal of the Schwarzman College is to "educate the bilinguals of the future". The term bilinguals describes the future graduates in chemistry, politics and history who will also be skilled in the relevant techniques of modern computing, further empowering them in their discipline. AI everywhere, just like statistics.

It is imperative we explore this concept in Australia. By integrating AI into the broader fabric of our university curricula, we can generate advances of unlimited potential in all fields, building the workforce and industries of the future.

I am counting on you to be the leaders in turning this vision into a reality and furthering the goals, aspirations and moral principles of our society. You are held to this benchmark precisely because you have always been at the forefront of our nation's proud record of upholding the highest standards of ethics while expanding the limits of science and knowledge.

I think of IVF, which started right here, as a combined research project between Monash University and the University of Melbourne. Building on the work of Professors Alan Trounson and Carl Wood, the first IVF baby, Louise Brown, was born in the UK in 1978. Australia's first, and the world's third, IVF birth took place in 1980 here in Melbourne under the supervision of a Monash University team, as did the world's next nine IVF babies.

But think for a moment about the torment of raw emotions that early prospective mothers experienced with this procedure. The conflicting anguish and hope. The gnawing fear that their IVF baby might be in some way abnormal at birth, or at age five, or 15, or 30. Fear, magnified in their minds by the overwhelming ethical and religious debates raging across society at the time. In most circumstances, these negative concerns would have prevented this new technology from ever being introduced. But they were outweighed by one powerful incentive – IVF's precious gift of matchless value.

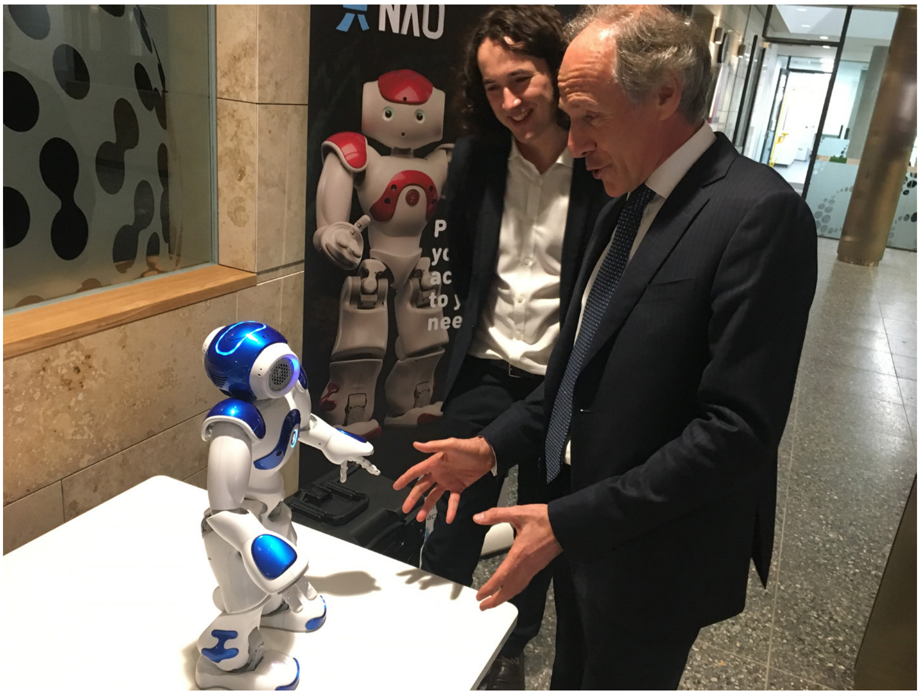


PHOTO: Office of the Chief Scientist

Today, there are more than eight million babies born from IVF. They are living proof not only of the wonders of modern science, but of our ability to keep our ingenuity rooted in our values. These babies are not just statistics. They are human beings who brought mothers, fathers, grandparents and extended families the joy of bringing a baby into the world. They are individuals who will experience birthdays, graduations, weddings, children of their own, and who, just decades ago, would not have had a chance at life.

It was precisely because of this extraordinary and visible benefit to individuals that we were able to work our way through IVF's novel challenges. And it is important to remember and acknowledge just how critical our university and research sectors were in solving these challenges and in shaping the multi-disciplinary framework behind IVF.

In 1982, the sizeable and extremely sensitive task of designing pioneering laws to govern IVF treatments was given to Monash University's own Professor Louis Waller, and I was saddened to hear of his recent passing. The Waller Committee report, which carefully considered the social, ethical and legal issues arising from IVF, directly led to Victoria becoming the first state in Australia, and the first government in the world, to regulate the practice of IVF. And establish the world's first central IVF register. And so, IVF became an accepted mainstream procedure.

Fast forward to the present, and it will not surprise you that artificial intelligence is contributing to improved outcomes. In a conventional IVF procedure, embryos are assessed by human beings – otherwise known as doctors – to choose which embryos to implant to maximise the likelihood of a successful pregnancy. AI is now helping to make that choice more reliable. At the forefront, is Australian company Life Whisperer Diagnostics, which emerged from the University of Adelaide. Its AI diagnostics product identifies the best embryos for implantation, with the goal of reducing multiple births and improving the pregnancy success rate. This a perfect example of how we can utilise the brilliance of AI to serve human needs.

And yet, while AI shows us how it can be of immense service to humanity, it cannot show us how to prevent its immoral use. That's up to us. And it requires constant vigilance.

Just this month, we learned that Google has obtained a patent to use an array of sensors and cameras to monitor home activity, with the capacity to work out the title of the book you're reading in bed. To put this into context, what if I proposed a complete stranger coming to your door and offering you unlimited free furniture and non-stick frypans in exchange for allowing them to camp out in your bedroom for the next two weeks and observe your, and your family's, behaviour? Would you agree? Of course not. We are repulsed by this prospect, not because of its unfamiliarity, but because we innately feel that it violates fundamental principles we rightfully hold dear. But Google wants to do that, not for two weeks but potentially for the rest of your life.

PHOTO: Group of Eight

The idea of treating humans as objects, as data to be studied and manipulated, rather than as cherished individuals entitled to inherent worth and dignity, stirs our deepest convictions. It crosses a moral boundary that needlessly encourages a conflict between science and ethics, which can only damage both our scientific endeavours and our nation as a whole. No matter how fast the pace of AI innovation, it must never surpass the primacy of human rights. Much will be lost if we discard our moral compass in the name of progress.

And yet, if approached correctly, this challenge can also be a golden opportunity for Australia. We can define our own future by being world leaders in the field of AI ethics and human rights. Showing the world how to advance the cause of scientific discovery while staying true to the ideals of a prudent and virtuous society. Like we did for IVF.

> ***"No matter how fast the pace of AI innovation, it must never surpass the primacy of human rights"***

To that end, in April this year, CSIRO's Data61 and the Commonwealth Department of Industry, Innovation and Science released a discussion paper to inform the development of an Australian AI Ethics Framework. In view of the emerging technological realities of AI, the framework aims to formulate new protections to build public trust, as well as help guide businesses and governments to responsibly develop and use AI systems.

At the same time, the Human Rights Commission, under the leadership of Ed Santow, is deep diving into the difficult issue of human rights and digital technology, and I am proud to be on the advisory committee. Of course, the Human Rights Commission, the government and the Australian community need to hear from universities about how to use AI for the benefit of all Australians. Not just from the computer science department, but also from our academic leaders in ethics, philosophy, law and business. As a reservoir of ideas, and a touchstone of our morality, input from across our universities will be crucial as we navigate the uncharted waters of promoting AI's promise, while safeguarding against its potential perils.

Working together, to help steer AI towards preserving and enhancing the quality of our lives, and the vigour of our ideals. As we go forward, I hope we will always be guided by our capabilities, our conscience and our collective human thoughts.

May the Force be with you.

34. Thomas Baker Oration

July 20 2016 | Annual Thomas Baker Oration to the Rotary Club of Melbourne

> The human brain is the most complex machine in the known universe, so it is no surprise that I refer to it often when I am asked to speak about future research challenges. Every time, I refer to it in awe. The human brain's complexity is well captured in my favourite quote about it, attributed to physicist Emerson Pugh: "If the brain were so simple that we could understand it, we would be so simple that we couldn't." Think about it. The brain is a moving target – at any given time, we know perhaps one percent of its workings, and the more we learn, the more we realise how much we have to learn. It took scientists four years to map a tiny portion of the mouse brain, containing 18,000 cells. The human brain has 100 billion cells. Mapping it is a task not beyond our imagination, but right now well beyond our capabilities. Which isn't to say we're not trying. The scale of research in this area is unmatched, and the advances – in bionic devices, electronic proxies and interfaces that can allow the brain to communicate with the body or with external devices – are exhilarating.

Tribute to Peter Rogers

Let me begin by acknowledging the prime mover of today's event, my great friend Peter Rogers, 99th President of the Rotary Club of Melbourne, who stepped down in June. Peter also has the distinction of being one of Monash University's first graduates, having enrolled in its first year. I won't say which year that was, but I am confident that the Rotary Club of Melbourne is older than Peter.

After graduating with his engineering degree, Peter began what would become a 20-year career with Imperial Chemistry Industries, better known as ICI, moving up from a domestic chemical engineer position to spend five years at its head office in London. An engineer is a valuable thing, something his employers obviously realised. Peter then went on to be a director for a number of ICI's international subsidiaries, as well as becoming a director of a London-based consultancy firm.

But Australia's charms can't be overstated, and he returned to the world's number one most liveable city, Melbourne. And Melbourne has welcomed him with open arms.

In 2009 Peter was appointed as the Chairman of the Monash Engineering Foundation. I was Chancellor of Monash University at the time and it was an eye opener for me to see Peter apply his tireless energy to diplomatically and strategically raising more than $25 million for the Engineering Faculty through strong emphasis on industry engagement with the university. Peter was also one of the self-styled pioneers who banded together to raise money to commission a magnificent statue of General Sir John Monash, a commemoration that was sorely lacking from the university till just last year.

Keyways and cornerstones

Of course, Peter belongs to a long Rotary tradition of influential engineers. In fact, the impact of the engineer is built into the heart of the Rotary brand. It's easy to miss, but if you look closely at the famous Rotary wheel, you see that the innermost circle has a tiny bump at the top. Let me tell those of you who don't already know, how that bump came to be.

In 1923 Rotary officially endorsed the wheel emblem, as a symbol of progress and endless potential. And then in rode a delegation of engineers, deeply concerned that the wheel as drawn was not mechanically sound. It had no keyway – the little slot required to lock a wheel into its power shaft securely. And without a strong power shaft, or a stable connection, that wasn't a system an engineer would trust. So forceful were these engineers that the addition of a bump was agreed. This, ladies and gentlemen, is an organisation that takes the trouble to get things right.

Thomas Baker: A fellow traveller

Now I am confident that if the question had been put to Thomas Baker in the Australian chapter of Rotary at the time, he would have endorsed the bump. After all, he started life as a wheelwright, like his father before him. And I look at his extraordinary winding path through life, and I can't help but doff my cap to a fellow engineer, come academic, come entrepreneur. His story will be known to many of you here today who still see the daily impact of his legacy. As the inaugural Thomas Baker orator, it behoves me to say a few words about him.

Born in Somerset, England, in 1854, Thomas Baker came to Australia as a lad of 11 in 1865. On finishing school, he worked first alongside his father, as a blacksmith and coachbuilder, and later as a pharmaceutical chemist. He married Alice Shaw, his partner in life, in business and in philanthropy, in 1877. The Bakers moved to Melbourne in 1881, where Thomas had a go at studying medicine, but was distracted by the new craze for photography, just teetering on the brink of the mass market.

He saw his opportunity. He set up as an importer and producer of photographic materials and rode the boom in amateur photography to stunning success. In just 13 years, he opened 14 stores – in Melbourne, Adelaide, Brisbane, Hobart and Sydney.

And let's not forget, he made the first X-ray film in Australia, in 1924. So Thomas Baker made his fortune in high-tech devices, and his fame in X-rays, with the instincts of a born engineer.

And my path is more or less the same – at least if you squint a bit. I was never a blacksmith, but I did take my degree in engineering, before turning to neuroscience for my PhD and postdoctoral research. Then I made my own ocean crossing, to Silicon Valley, to set up in business. My company made precision tools for diagnostics and research. We ended up not in X-rays, but making their descendants – scanning imaging systems for reading the gene expression off DNA microarrays.

Thomas Baker
CREDIT: Rotary Club of Melbourne

Thomas Baker was also known for tooling down Swanston Street in a Rolls Royce. Today, well, he'd be like me, and he'd glide down the main street in a Tesla electric car! And I, like all of us here today, would be very proud to depart this life with a legacy half as rich as he left behind.

Thomas and Alice Baker were born with the Rotary ethos in their bones – service above self. And it shines through every chapter of their lives, from their contribution to the war effort, to their generous and anonymous bequests, to the national treasure they built, in the form of the Baker Institute.

This city would not be the great hub of biomedical innovation we know today were it not for leaders of their calibre. This country would not be a global player in medical science and an important partner in global health. And we would not set out on life with the expectations of health and longevity that we do today.

A woman born in Australia in 1900 could expect to live to 57, and a man to just 54. And no, that figure doesn't include the lives cut short through war. A person living out their life in the ordinary way wouldn't, on average, live to see 60. In just four generations, we have added more than 25 years to the average female life, and close to 24 years for males. Even better, as our lives extended, so too has the period we expect to enjoy without disability. It would not be possible without medical science, and those like Thomas and Alice Baker who helped to fund it.

Nor would it be possible without people like the Rotarians, spreading the fruits of progress right across the world. There is no better contemporary example than the quest to eradicate polio, which Rotary and the Gates Foundation lead today. So in honour of Thomas Baker, and all Rotarians past and present, I've been asked to give a small taste of the future in medical sciences.

Introducing, the brain. I can't do justice to it all, so I've chosen to focus on that stretch of the horizon that excites me the most. Or it would excite me the most, if I wasn't Chief Scientist, and obliged to be permanently excited about everything.

The quest I want to talk about today is the drive to understand the human brain – to map it, to model it, to rebuild it. Why does it intrigue me? I've been watching this field now for 40 years. In that time I have developed an empirical rule, a bit like Moore's Law about the rate at which computer chips improve. My empirical rule is that whatever we know about the brain at a given moment in time, it is only about one percent of what there is to know. In other words, the brain is so complicated that knowing how it works is a moving target, always receding into the future. The more we learn, the more we learn there's more to learn.

But just look at the relentless determination with which we are pursuing that target today. Two years ago a group of scientists trawled through the massive database of all the research papers published since 2010. They identified 1.8 million papers on the brain. Of every six science papers published on any topic whatsoever, one was about the brain.

> *“Whatever we know about the brain at a given moment in time, it is only about one percent of what there is to know”*

But that’s not surprising, because researchers learn to be very good at following the money. The Americans have a Human BRAIN Initiative. In this financial year alone, they’ll spend A$565 million on that program. And this program is not to be confused with the Human Brain Project – the €1 billion project from the European Union. Or the Brain Institute, a private initiative backed by $US500 million from Microsoft co-founder Paul Allen. In nation after nation, brain research is the hot-button field, including our own.

And even if you don’t read scientific papers you can’t miss the interest in the mainstream media today. The promises I see in the headlines are certainly enticing. We’ll have cures for dementia – tomorrow! We’ll have temple-to-temple electronic brain-zappers to speed up our thoughts! We’ll have chips in our brains that make us demi-gods communicating by telepathy, and lifting objects and bending spoons with our minds! Or, in the greatest dream of geekdom in our time, we’ll be able to upload our brains entirely into an ultra-powerful silicon computer. If achieved, our bodies might decay, but our minds would be immortal!

This is no exaggeration of the reports in the media today. There are people, even as we speak, downing a cocktail of pills in an effort to extend their lives, so they are ready when the day to be uploaded comes.

The scale of the challenge

However, the reality is that we are generations if not centuries away from the knowledge to even contemplate that path to immortality. Let me put it this way. Last week, the Allen Institute for Brain Science released perhaps the most detailed map of an advanced mammal brain ever created. It shows the electrical activity in a tiny portion of the cortex of the mouse. There are 18,000 brain cells in that map. It took more than 100 researchers more than four years to create it. And it has been hailed across the world as a major triumph.

Now hold up a finger. Look at the top segment. Think of a piece of human brain tissue about that same size. Instead of just 18,000 cells, a bit of human brain tissue that size contains around 50 million electrically active brain cells and close to a trillion connections between them. Then imagine your adult brain: 100 billion cells, quadrillions of connections, and constantly changing. Connections form and dissolve. Neurons retrain for different jobs. Growth hormones ebb and flow through the network. Are we close to understanding it? No.

Now let's return to the great dream of immortality by uploading your brain into a silicon computer. To start, you would have to scan a brain such as yours at molecular detail to capture every single connection between your brain cells, and to identify the exquisite unique chemistry and electrical activity that makes you, you. The trick is to do that while your brain is still healthy, and to do the scan without having to sacrifice your existence to the process. Do I recommend this? No way. I'm a techno-optimist, but not a fantasist.

The process would be gruesome. It would start by using an ultra-sharp diamond blade to shave your brain into slices. Each slice would be as wide as your brain, about half the size of a sheet of paper. But in thickness each slice would be thinner than a thousandth of the thickness of the sheet of paper. All up, there would be 10 million slices of brain tissue. Your brain tissue. Then we'd use an electron microscope to image each slice, stack up the 10 million layers, and hey presto, a map of your brain.

Of course, we still wouldn't understand the operating code – the processes which underpin memory, thought, dreams, and your sense of self. And we still wouldn't know how to build a silicon computer with a fraction of the processing power your brain packs into a cubic centimetre of tissue. Even if we did, with today's technology it would occupy dozens of hectares and consume enough electricity to power the Melbourne CBD.

> ***"We and our children will be the beneficiaries of technologies that were themselves the stuff of fiction when we were young"***

So, any volunteers? But before you put your hand up, I warn you: like Humpty Dumpty, all the king's horses and all the king's men couldn't put your 10 million brain slices together again. Well then, friends, we'll have to forego our bid to be gods. But nevertheless, we have the privilege of living in fascinating times. And we and our children will be the beneficiaries of technologies that were themselves the stuff of fiction when we were young.

New breadth of opportunity

The progress in bionic devices in the past two decades has been extraordinary. And this city can take a great deal of credit for the poster child of this golden age, the Cochlear implant.

It stands amongst other breakthrough bionic technologies on the market today:

- Spinal cord stimulators for the treatment of chronic pain;
- Nerve stimulators for the control of epilepsy; and
- Deep Brain Stimulation for eliminating tremor in conditions such as Parkinson's disease.

I am very proud to be one of the philanthropic contributors to the next-generation technology, the bionic eye. The bionic eye in development at Monash University uses a camera to see the world, and around 600 electrodes planted into the visual cortex under the skull, deep in the brain. The quality of the image is spotty but it will get better with time.

Beyond the bionic eye, the multi-lane highway to progress

I'm not just inspired by the promise of restoring vision to the blind, although that alone would be reason to support this research. But for me and for Australia there is the excitement of standing on the great frontier, in the company of fellow thinkers across the world. Just think of all we need to accomplish to make bionic vision – great bionic vision – a reality.

We need to work out how to process colossal volumes of data in wearable devices. We need to develop new materials to make implantable devices that are strong, light and durable. We need to develop new methods of manufacturing to make electrodes that work with phenomenal precision, even as the brain tissue tries to reject them as foreign bodies. We need to accelerate the development of artificial intelligence and machine learning, to make sense of a constant storm of visual signals.

And let's not forget the cybersecurity threat. We know that Mark Zuckerberg, founder of Facebook, puts masking tape over the camera on his laptop. Why? For fear it will be captured by hackers. Imagine if your bionic eye was internet enabled, to transmit data to your doctor, and perhaps to download upgrades, just like my Tesla car. What if hackers could see through your eyes? What if hackers could control your eyes? Let's move on.

The upshot is that building a bionic eye means building the potential for many other breakthrough solutions, from computer processing to super-durable materials.

And it's not just the bionic eye. The next most exciting development is a means to restore full movement to the paralysed limbs of paraplegics and quadriplegics, which is still at a highly experimental stage in Utah.

Deep questions, complex answers

All of these technologies raise hard questions for our society, questions that will only become more complex over time.

Today, there is the problem of misinformation, and the people who seek to profit from it. I am speaking of those snake-oil salesmen who offer false hope to desperate people. I am speaking of the shoddy pseudo-science that we see presented as "neurological research" to flog a self-help book or back up a dubious opinion. And I am speaking of the trouble we often have as a society in separating the hype from the reality when a complex field of knowledge is moving fast.

How are we going to disentangle what is from what will be with so many hucksters to mess up the threads? On the horizon, I can see other questions that will emerge as the science progresses and our technologies improve.

We know that all cutting-edge technologies are expensive, and the Cochlear implant is a good example. An implant and speech processor can cost up to $30,000. The surgery and clinical costs add to the bill. And that's the start. Like any consumer device, you have the lifetime costs – upgrades, new batteries, routine maintenance, perhaps repairs. It is still much cheaper than the lifetime costs of a severe hearing impairment, but it adds up. And that is evident in the take-up rates for the Cochlear implant across the world.

In Australia, almost every child who is clinically eligible for a Cochlear implant receives one, a coverage rate of 97%. In the United States, the coverage rate is 50%, which means that one in two children will miss out. But even countries like ours, with a strong public healthcare system, have to prioritise access to the resources, and because we prioritise children, adults go to the back of the queue. Adult coverage is less than 10% in this country, and everywhere in the world.

If we can give sight to the blind, who would deny it? But wouldn't we say the same of technologies that might save lives, cure depression, allow the paralysed to dance? So how will we prioritise our resources to support the research, and then maximise the access to cutting-edge care?

Then there are the even more mind-expanding questions, as the technology tips from treating problems, to enhancing people. How long until we see bionically enhanced athletes? How long until we see the early adopters of the world line up for superhuman hearing and vision, or super-strength arms and legs? How long until parents treat their children as works in progress in every sense – from gene editing before birth to regular bionic upgrades during life? Perhaps a century; perhaps a generation.

But all along the way, with every new technology, we will be asked again and again to think about drawing the lines. Are we ready for the challenge that presents?

Revelling in the tides of progress

There are already calls across the world for humans to put the wheel of progress into reverse. I'd say that's about as likely as holding back the tide. It can't be done.

That doesn't mean we can't enjoy a day at the beach. And perhaps we can take a lesson or two from the fine Victorian surf-lifesaving tradition, as we wade into the churning waters ahead. How do we keep people healthy, happy and safe? We educate them on water safety. So too we can educate ourselves in science, technology, engineering and maths. We build a water-safe, beach-loving culture. So too we can get people interested in new technologies. We study the mechanics of the tides to get better at seeing the rips. So too we can learn a great deal from studying both the present and the past. We get the best weather forecasts. So too we can cast our minds forward, with the help of scientists, economists, artists and many others, to prepare for the developments coming our way. We put out flags, and so too we can develop sensible regulations that enable progress while ensuring safety and equity. And most of all, we don't lose sight of the reason we go to the beach in the first place. Because it's fun. Because it makes life richer. Because it's in our blood to hear the call of the sea.

> ***"It is in our blood to learn, invent and discover"***

So too we must not lose sight of the reasons we embrace progress. Because it makes us healthier. Because it increases our prosperity. And because it is in our blood to learn, invent and discover. And friends, it's also in our nature to reach for the better way. To imagine it, and to realise it, just as Thomas and Alice Baker set out to do, all those decades ago. So let's celebrate their great legacy today, and keep turning that great wheel for tomorrow. After all, I'm an engineer, so I know that the Rotary wheel is sound.

35. Better than Brilliant

August 22 2017 | Opening Address to the IEEE Sections Congress in Sydney

> It is stunning how many times the technological breakthroughs I thought would never happen in my lifetime, if ever, have been achieved. Detection of gravitational waves. Optical microscopes that see intracellular structures at the molecular scale. Video conferencing that works! Then there is AI. The bots can do a fast increasing set of ever more complex tasks, often better than we humans. But they must be taught and tamed by something we can only call humanity – for which the definition might be fuzzy, but you know it when you see it. As we humans find ways to coexist with artificial intelligence, three guiding principles should chart the way. One, skill up in the language of computing; don't dumb down. Two, instil the very human value of empathy in our science, technology and engineering workforce. And three, regulate the bots with a robust set of laws. And there is a fourth. Stay close to the off switch.

When I saw the topic for this event, "brilliant minds, bright futures", I grew excited. Hooray, I thought, it's a neuroscience convention! Well, it's not a neuroscience convention. If it's possible, it's even better – the global congress of the IEEE.

I'm proud to say that I'm a Fellow, a card-carrying member. And I'm a member because I believe in the incredible power of the human mind. I believe it because I've seen it up close. During my PhD in electrical engineering, I was fortunate to be drawn into researching the electrical activity of the brain. Thus began my second career, as a card-carrying neuroscientist.

I was captivated by the meticulous drawings of Ramón y Cajal, the father of modern neuroscience, dating from the 1890s. To me, he was the Leonardo da Vinci of his time, a scientist and an artist combined. He opened my eyes to a web of such fabulous complexity that I knew I could happily spend a lifetime trying to grasp it.

In my day, we were told that we would never be able to use a microscope to observe any features smaller than 200 nanometres. We were working to the old Abbe diffraction limit, which, at the time, had the stature of a law. Even with a perfect lens, Ernst Abbe said, there was a fundamental limit to seeing small objects. You could never see anything smaller than half the wavelength of the illuminating light. So we could see whole brain cells, which are several thousand nanometres wide, but not the tiny neurotransmitter capsules that fill the synapses.

We were also told that replicating human intelligence was an impossible dream. Research funders the world over were absolutely convinced that there was no way a machine could reason or learn or create, like a human. Never ever, no way. In my lifetime, I've seen the impossible become the everyday. We've smashed the Abbe diffraction limit by much more than a factor of 10. We've literally lit up our image of the brain. And when we lit up the brain we awoke to the possibility of reverse engineering intelligence itself.

There are very few examples of genuine biomimicry – that is, technologies developed by working backwards from phenomena in the natural world. Our aeroplanes don't fly like birds, even if birds showed us that flying was possible. Our submarines don't flap their tails like dolphins, even if dolphins were the proof that high-speed propulsion under water could be achieved. But unlike birds and dolphins, the human brain has become an incredible well of ideas – literally, a brains trust for humanity, with a wealth of ideas to pinch.

> ***"All these human things are inspiring geniuses such as yourselves to develop a new generation of thinking, learning, intelligent machines"***

Our brains are neural networks, with multiple memory systems split across short term and long term storage. Our every thought depends on negative feedback. We have a propensity to continual learning. All these human things are inspiring geniuses such as yourselves to develop a new generation of thinking, learning, intelligent machines. A revolution in a blink of history. The dawn of the artificial intelligence age. And perhaps the twilight of humanity as we know it. It's all there, in our brilliant minds.

* * *

Which brings me to the speech I promised you in the program: AI, automation and jobs. By now, you probably think you've heard that speech before. First, they came for the factory workers, the manual jobs. Then, they came for the secretaries and the bank tellers, the process jobs. Now, they're coming for the architects, the lawyers, the doctors, and yes, the engineers – the cognitive jobs and the creative jobs. The AI threat to jobs is now impossible to confine. No job, however prestigious, however complex, is safe.

So what next? As an optimist, I'd tell you that there will be new jobs in place of the old. As a pessimist, I'd encourage you to prepare for life on Mars. As a transhumanist, I'd suggest some upgrades you might want to consider installing in your brain. If you can't beat the robots, be a robot. As an economist ... no, I'll let the economists explain themselves.

But optimist, pessimist or transhumanist, the message is always the same: embrace disruption. I look out at the audience today, and I realise that particular message is completely, utterly redundant. You, the members of the IEEE, don't need to embrace disruption, you live it. You live it, breathe it and sell it. Gram for gram, you probably pack more disruptive potential than any other gathering of human beings at this moment, anywhere on Earth.

So you don't need me to teach you your trade. Instead, I want to throw down a challenge. I want to challenge you, the world's best possible design team, representing the world's greatest possible supply of disruptive potential, to automate me. I want us to imagine the best possible AI Chief Scientist based on the technologies either available today, or in the foreseeable future. Call it ChiefBot. And then, I'm going to challenge myself to make the case for employing a human.

PHOTO: IEEE/Twitter

And if I can persuade you that humans will still be required, I want to draw some conclusions about how we can sharpen humanity's competitive edge. Not just in my job, or your jobs, but in all jobs – manual jobs, caring jobs, creative jobs. I want to persuade you that we can all find ways to be better than our brilliant machines for generations to come. And not just better than our machines. Better off because of our machines. Better together.

I've got a lot on the line. So here goes. This is a list of the tasks a ChiefBot would be required to do. Deliver speeches. Easy. There are hundreds of free text-to-voice programs that wouldn't cost the taxpayer a cent. Naturally, I would adapt the settings to sound like David Attenborough.

Write speeches. Again, easy. Google has an AI system that writes poetry. A novel by a robot was shortlisted in a Japanese literary competition. And an American student has developed an AI for speeches. That AI system draws on a database of several thousand speeches to the US Congress. The mind boggles. I have a personal database of several hundred speeches, and many more articles and emails. So there's scope.

Next, scan the science landscape and identify trends. IBM Watson can already do it. After it graduated by beating the humans in Jeopardy! it took on a new career as a doctor. But Watson can do more than just scan millions of pages of scientific reports to diagnose tumours and recommend treatments. It's a talent scout for professional teams in the NBA. It matches guide dogs to people. It helps wineries and airlines to maximise their profits. It's had more careers than Barbie. So why not add another?

Next, serve on boards and make complex decisions. And ChiefBot wouldn't be the first robot to serve in that capacity. It wouldn't even be the first in this country. For example, there's a company in Tasmania, here in Australia, that sells AI software to advise company boards on takeovers. There's a company in Hong Kong that's gone one step further and actually appointed a robot director.

Next, understand politics in Canberra and Washington. If a robot can do that, it can probably build the Hyperloop. But speak, write, research and decide – all of those functions could certainly be packaged into an immortal, impartial, apolitical form.

So, there's ChiefBot. I admit, it's pretty good. Brilliant, in fact. And it's only going to get better. I have to assume that ChiefBot will capture all the benefits of machine learning, high performance computing, the Internet of Things and robotics.

I also have to assume that my own data retention and processing speeds are unlikely to improve. But let's not abandon our faith in humanity yet. Here's my case for human.

First, a simple but obvious point. I can be better than brilliant because I speak fluent human. I use words with an understanding of their nuance and impact. And I don't just speak *in* human, I speak as a human. A robot that says that science is fun is delivering a line. A human who says that science is fun is telling you something about what it means to be alive.

> ***"A human who says that science is fun is telling you something about what it means to be alive"***

And I know. I know what it's like to be a child. I know what it's like to earn a PhD, be a parent, start a company, lead a team. I know what it's like to submit a report and eagerly wait for it to be adopted. I know what it's like to find these things both impossibly hard and endlessly rewarding. I also know that nothing is more irritating to the humans who write to me because they care, than to receive an automated response from a system that doesn't. A system like ChiefBot.

So better than brilliant means fluent in human.

Second point, I'm limited, by design. As human beings, we are bound by certain constraints. We are bound in time – we die. And we are bound in space – we can't be in more than one place at a time. In practical terms, it means I can't say yes to every event. So when I speak to an audience, I am giving them something exclusive, a chunk of my time. It might be a good speech, or it might be a terrible speech, but I can guarantee, it will be a one-off, never-to-be-repeated, 100% robot-free delivery. And it has value to you, as a mark of my respect.

Of course, I could also prerecord a message, livestream an event or post the video on YouTube. And I do take advantage of those technologies to work around my human limitations in time and space. But it hasn't stopped people from inviting me to speak in person. So digital Alan alone is insufficient. Digital Alan's role is to build the market for human Alan, just as YouTube builds the market for arena spectaculars and live performances.

I see the same pattern repeated across the economy. Thanks to technology, goods and services are cheaper, better and more accessible than ever before. We like our mass-produced bread, and our on-tap lectures, and our automated FitBit advice. But automation hasn't killed the artisan bakery. On the contrary. Online courses haven't killed the bricks-and-mortar university. On the contrary. And FitBit hasn't kill the personal trainer. On the contrary. All of those things are booming, alongside the machine equivalents. The robot, and the robot-free zone.

So better than brilliant can be limited, by design.

Third point, I can be flexible and effective in human settings. In our world, AI is the interloper. We are the incumbents. It's the robots who have to make sense of us. And let's face it, we make it difficult.

Think, for example, of a real-estate negotiation. We could rationalise it as an exchange of one economic asset for another. But in reality, I know that there's every chance that I will raise my bid because there was a lemon tree in the backyard and it reminded me of Aunty Gerda's lemon pie. And then I'll withdraw from the negotiation to be strategic. And then I'll panic and raise my bid again.

These decisions make sense when we account for all the things that influence we humans, like sentiment, insecurity and peer pressure. But there are so many possible permutations of Human 1, the buyer, and Human 2, the seller, that the negotiation will never follow a predictable path. The art of the real-estate agent is to anticipate, pivot and nudge.

And the human real-estate agent, she's the package deal. She can harness AI to sharpen her perceptions and overcome cognitive biases. Then she can hit the human buttons to cajole, deflect, flatter or persuade. That human touch is hard to replicate, and even harder to reduce to a formula and scale.

So better than brilliant means flexible and effective in human settings.

Fourth, I've learned the habit of civilisation. Let me illustrate this point by a story.

A few years ago, some researchers set out to investigate the way that people interact with robots. So they built a small robot and sent it off to patrol a nearby shopping mall. When the robot encountered a human, it would politely ask the human to step aside. The outcomes of this experiment are summarised in the title of the subsequent report: *Escaping from Children's Abuse of Social Robots*.

Yes, that robot had a terrible time. It was beaten by children with plastic bottles. It was smacked in the head with a soccer ball. It was kicked, bullied, obstructed and called what the researchers delicately referred to as "bad words". The more children in the group, the worse they behaved. When asked why they attacked the robot, the top reason was "for fun". The researchers decided that the most reliable way to protect the robot was to program it to steer clear of humans shorter than 1.4 metres.

But Alan, that's a terrible story, you'll say. Well, yes, it is. But the point is not that the children were violent. The point is that the people above the 1.4 metre threshold were not violent. The adults in the shopping centre were able to restrain whatever primitive impulse they felt to smack something smaller and weaker in the head. The adults had absorbed the habit of living together. Civilisation.

And when you think about it, it's an amazing thing. Take electricity. It's probably the most dangerous substance that we handle day to day. And yet it's available to us at the flick of a switch. We've tamed it. And that was only possible because we tamed ourselves, through layers of regulations and standards and industry codes and market incentives and cultural norms. Human systems. Human systems that put technology to work for humans.

And if we want artificial intelligence for the people, of the people, and by the people, then we will need to remember what we've learned over thousands of years. Better than brilliant means civilised.

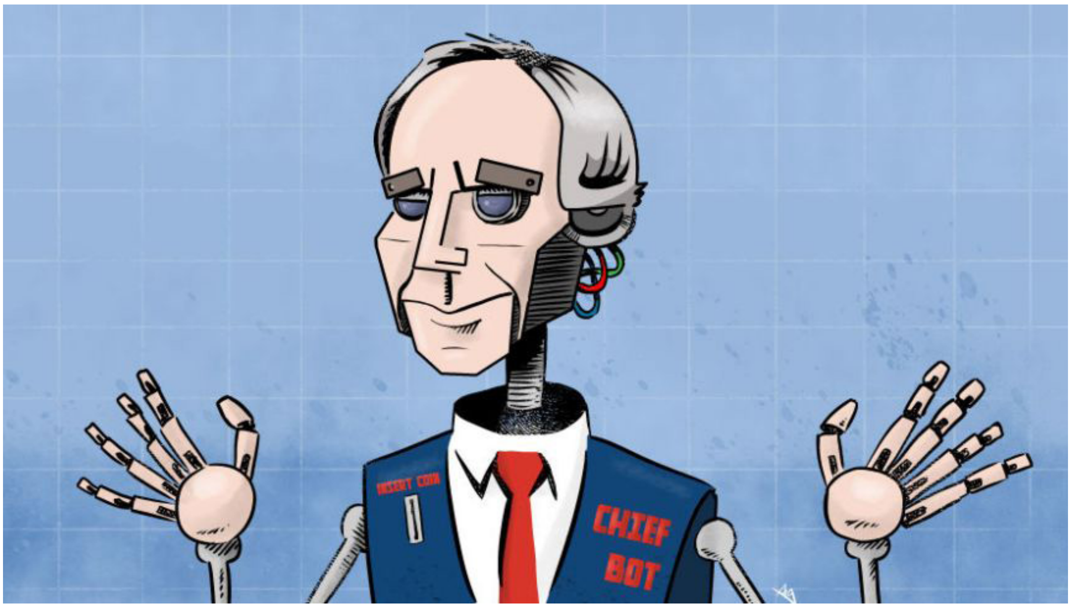


IMAGE: Wes Mountain

Together, these four points suggest to me that humanity has a powerful competitive edge. We can coexist with our increasingly capable machines. And there is plenty of room for all of our human talents to flourish, whether we want to build the robots, harness the robots, civilise the robots, or create a robot-free zone. But if we want that future, we have to claim it. People call me a techno-optimist because I believe humanity can do it. You, the technologists and engineers, you are the torchbearers. I rely on you.

Let me suggest three things that we can do, as individuals and as a global movement, to sharpen humanity's competitive edge.

First, we can resist the temptation to let humans dumb down. I have seen that temptation expressed in many ways. There is the argument that we don't need advanced maths and science in schools. And there's the suggestion that you don't actually need to learn a discipline, or any hard content, because all the information you could ever need is available on line. And Siri or Alexa can find it on your behalf. I strongly disagree. The evidence suggests that workers will need to make their niche in a fluid and unpredictable environment. That suggests to me that we need to be more capable, not less.

Let's work backwards from the skills we need in our university graduates. At a minimum, they need to master a discipline. By mastering a discipline they learn how to learn. With a discipline under their belts, they can enter a professional community with the mental toolkit to allow them to learn from their peers. They can learn about leadership and life in a job, and then they can make new jobs for others as well as themselves.

But to master a discipline in the first place, they need to have strong foundation skills in language and maths. With language and maths, they can tackle science and technology. So we have to grab them young and keep them going. Then they can enter the artificial intelligence age with the capacity to hold their own. So skill up, don't dumb down.

Second, we can improve our fluency in human. As engineers, we are trained to think and speak in systems. But the essence of engineering is people. It is the capacity to design around our human limitations so that we, as a species, can transcend them. It takes a grasp of how humans behave, and an understanding of what humans want.

We call that empathy. It's the difference between the engineer who designs a product, and the engineer who delivers a solution. We don't teach our students a formula for empathy. We haven't got one.

My alternative is to advise them with a single word, respect. Respect the intelligence of your audience. Respect their right to participate in the debate. And respect your rights and responsibilities as an expert, someone worthy of trust. With respect, you can't go too far wrong.

Third, we can embrace … wait for it. We can embrace regulation! I'm serious. Let me explain. If someone told you that we must resist AI because it's dangerous, you would disagree. No, you'd say, AI is a tool that we can use in either good or harmful ways. I'd say the same is true of regulation. It's a tool.

Bad regulation is an impediment. But so too is no regulation, when it results in consumer backlash or investor uncertainty. What we need is effective regulation to give our society the confidence to experiment. Effective regulation sets the rules that allow you to contribute to our human future. So let's be proactive in making the case.

The IEEE gets it. It's the essence of the IEEE Global Initiative launched last year for Ethically Aligned Design. How often do you come across a paper from the tech community that begins with a statement like this: "Human wellbeing is the highest virtue for a society, and human flourishing begins with conscious contemplation."

It goes on: "Our mission is to ensure every technologist is educated, trained, and empowered to prioritise ethical considerations in the design and development of autonomous and intelligent systems."

That is the tech community I recognise. A community of intelligent and articulate people, with a genuine desire to make the world a better place. It's a community to which I'm proud to belong.

So skill up, show respect and regulate the smart way. And of course, embrace disruption. But you knew that. After all, you're better than brilliant. You're brilliantly human.

36. Delivering the Future

May 8 2018 | Opening Speech to the Australian Road Transport Suppliers Association Global Leaders' Summit

My friend, Peter Hart, presented a trucking 101 course to me before my speech to the Australian Road Transport Summit. It's a great course for administrators wanting to learn how to do regulation right. The key lesson is that progress comes from consultation, consensus, and a focus on performance rather than black letter law. Advances in the trucking industry provide lessons for new tech, especially as the world looks for safe ways to transport hydrogen, the energy of the future. As trucks became semi-trailers then B-doubles, the industry had to overcome resistance from governments and convince the public the technology was safe. Then came giant autonomous haul trucks in the mining industry, and next comes platooning – convoys of heavy vehicles operating tightly together and controlled by artificial intelligence. Australia is well placed to be a world leader in this technology. We must aim high, developing the best technology and the highest safety standards to ensure the public comes along for the ride.

To the best of my knowledge, I am the first Chief Scientist to appear at a trucking convention. So let me tell you how I got here. It was November 2016. I'd been invited to give a talk to the leaders of our universities about the way we ought to ensure quality teaching and learning across the sector. I promised the organisers that it would be a fascinating speech. And it would be particularly exciting, because I was going to talk for half an hour about regulation. It's one of my favourite topics.

In all seriousness, I've said for a long time that regulation, good regulation, is a business's best friend. You know regulations are good if they do two things. First, protect the public. Second, facilitate progress. They're both important. They're equally important.

But I needed an example that would sum up all the benefits of regulation done right. So I got in touch with my friend Peter Hart, the chairman of the Australian Road Transport Suppliers Association. And Peter said to me, "Alan, have you ever considered trucking?" To my shame, I hadn't. Peter proceeded to deliver Trucking 101.

And I quickly realised that there was a gap in my awareness so big you could drive a 60 tonne truck through it. Or as I now think of it, thanks to Peter, a 60 tonne higher productivity freight vehicle. And ever since that day, I've been looking for an opportunity to meet with the industry and say, well done. You know the story, but let me tell you how I explained it to the higher education experts, and the lessons that I wanted to highlight.

Anyone who looks at a map can see that Australia is a country that's going to suit big trucks – long distances, low rural population density, big cities. As the population boomed in the aftermath of the Second World War, so did the demand for road freight. More trucks on the road meant more congestion, more pollution and inevitably, more accidents.

Then the B-train emerged in Canada in the 1970s – two trailers behind a single prime mover. Here was an answer to the problem, a vehicle only slightly longer than existing semitrailers, but carrying a much greater payload. Resistance was fierce, particularly in Victoria, where the headlines were filled with dire warnings about these Canadian "road monsters". That's not a truck, they said. That's "sheer murder". Every state and territory government had to be separately convinced.

And then, in 1989, right as Victoria, the last great stronghold of the resistance, was finally prepared to come to the table, more than a decade after the idea was first floated, the Grafton tragedy occurred. A collision between a semitrailer and a bus that claimed 21 lives. It was the worst road accident that the nation had ever seen, and it put the spotlight on all the reasons to be afraid of big trucks.

The trucking industry could see the advantages of B-double combinations – improved productivity, reduced congestion, fewer crashes. But you had to make the case on evidence, to ministers and to the public. And you did. Today there are more than 10,000 B-doubles on the roads and they carry more freight than any other vehicle configuration in Australia.

PHOTO: ARTSA

But even more extraordinary than that success was the follow-up. Because you didn't do what human beings normally do after they achieve something that took a lot of effort and a very long time. You didn't stop. You saw the need to keep going.

And you took that twofold objective of good regulation – remember, protect the public, facilitate progress – and turned it into the Performance Based Standards. This was a world-first – a comprehensive legal framework for higher productivity vehicles in exchange for more stringent safety requirements, operating right across the country, and governed by a national regulator. It puts the focus where it needs to be for an Australian industry to be genuinely competitive, a focus on quality and on innovation.

But that's not all that I discovered about Australian trucking. The more that I looked into it, the more impressed I was.

> ***“It puts the focus where it needs to be for an Australian industry to be genuinely competitive, a focus on quality and on innovation”***

If you read the newspapers, you could conclude that we don’t make vehicles in Australia. We do. We make trucks and trailers. And it’s a $7 billion manufacturing industry, centred right here in Victoria.

Another interesting fact that we ought to know: this country is the global leader in autonomous trucks. Rio Tinto has almost 400 giant haul trucks operating in the Pilbara. And 20% can drive themselves, with supervision from the control centre in Perth. This year the company clocked up one billion tonnes of material, moved by autonomous haulage, with zero injuries.

There’s more. Australia is also a global leader in driver monitoring. Many of you will know of the company Seeing Machines. It was formed as a spin out from the Australian National University. It got its commercial kick start working with Caterpillar, making driver-fatigue technologies for the mining sector. Today Seeing Machines is enjoying the first sales of its driver monitoring system for use in passenger vehicles and it’s working with Monash University to develop the gold-standard platform for heavy-vehicle fleets.

Another opportunity: blockchain. Consumers overseas will pay a premium for Australian produce if they can trace the provenance. Blockchain means that a buyer in China can pick up a T-bone steak, scan the barcode, and get the history of the cow – date of birth, name of the farm, type of feed.

Look at the technologies at the core of each of these initiatives. Artificial intelligence. Data and analytics. Blockchain. That’s the 21st century frontier. And we are getting to that frontier in trucks.

Now it ought to be impossible for success in the form of a very big truck to fall off the national radar. But as we know, it’s really not so surprising at all. It’s simple: you don’t make headlines with truck crashes that didn’t happen. And even when we do pause to acknowledge progress, we just adjust our expectations.

The CEO of Amazon, Jeff Bezos, wrote about this phenomenon in his latest annual letter to shareholders. In his words: “We didn’t ascend from our hunter-gatherer days by being satisfied. People have a voracious appetite for a better way, and yesterday’s ‘wow’ quickly becomes today’s ‘ordinary’.”

Now this is the leader of a company that sends out over five billion parcels, every year. So Jeff Bezos understands at least two things. Trucks. And customers. His ethos, as he explains it, is straightforward. Have high standards. Widely deployed, relentlessly enforced, to the point where other people may conclude you’re being unreasonable.

I was lucky. I got that advice at the crossroads of my life. I was a nervous young man, newly arrived in San Francisco, and trying to establish my own medical device company Axon Instruments.

There was a time when I’d close my eyes when I went to an ATM because I lived in terror that there would be nothing in the account for the machine to give me. I’d worked very hard and I knew I had designed a quality product, better than anything else on the market. But it was also a lot more expensive, twice as expensive as the competition.

I made a desperate phone call to a very wise mentor, Eric Charles, back home. And he gave me some of the best advice I've ever received: quality is remembered long after price is forgotten. We could write that on the side of Australian trucks.

And perhaps that's a good theme to take into today's conference, as the leaders of a $7 billion industry, at the heart of Australia, and vital to its prosperity. How are we going to carry that expectation of high standards into the future, and not just for trucking, but as a standard-bearer for all Australian industry?

Let me suggest that it's worth thinking about the challenge as a combination of two important dimensions. The first is the way that every player in the industry conducts themselves day to day, as custodians of the public trust.

Trucks are visible to the public in a way that other technologies are not. Every truck is a mobile window into the industry. So you know better than most that public trust is a slippery commodity. The instant you relax your grip, it's gone.

I have been reflecting this week on what happens when you relax your grip in another tightly regulated field, the field of medical research. Like trucking, it's regulated for a reason. If you think that securing approval for a new vehicle configuration is hard, try getting approval to put new drugs into human beings.

There's a second important quality assurance filter for scientists, in the form of peer review. Before your work is published in a journal other experts in your field will scrutinise it to ensure that every single contribution to the great repository of our scientific knowledge is sound.

But very occasionally, something slips. And 20 years ago, something did slip. A paper was published in the medical journal The Lancet. It claimed to show evidence of a link between vaccination and autism. Sadly, it didn't meet the definition of science. The author was an ideologue out to make a point. He engineered the study to give him the outcomes he wanted. And even then, he didn't get them. So he took the next step and manipulated the data. This wasn't science. This was fraud. It should never have been published in a journal. But it was.

Twenty years later we have a resurgence of measles due to poor immunisation coverage in developed countries, including close to 15,000 cases and at least 37 fatalities in Europe, last year alone. Scientists call that paper a zombie. It doesn't matter how many times you kill it, it always rises again. And it comes back with an army of undead zombie friends, spreading fear across the community, not just of one vaccine, but of all vaccines.

The hard lesson of that story is that the cost of a lapse in standards is always too high. The best protection against criticism is to always do whatever it is you're doing extremely well. So that's the first dimension to consider – how to embed high standards across the industry, so that every person adheres to them, every time.

> ***"The best protection against criticism is to always do whatever it is you're doing extremely well"***

The second dimension is the work you do as an industry to ensure that regulation keeps pace with technology. In many ways, trucks are going to get to the future first. We had autonomous trucks on mine sites long before we saw the first hint of autonomous cars on suburban roads. And we've had routine driver surveillance and monitoring technologies in trucks for some time.

From left: Mr Sal Petroccitto, Dr Alan Finkel, Dr Peter Hart
PHOTO: ARTSA

But getting to the future first means steering into unknown territory and trying to haul the community along. For example, I think about platooning, a convoy of heavy vehicles, linked by vehicle-to-vehicle communication, following closely one after the other, and automatically accelerating and braking together.

What the industry sees is the capacity to improve fuel efficiency, reduce costs and boost the safety of road freight. What the public will see is a line of tailgating trucks. And what governments will see is a significant risk in the event of a malicious hack, or a simple computer glitch. Regulators will need to be satisfied that the industry can align the very high standards that we expect in trucks, with the rapid response capacity that we expect in software.

So look at our history of performance based standards, and our expertise in autonomous trucks. Which country is better placed than Australia to work out how to regulate effectively in the intersection between trucks and tech?

Another example: improving fuel economy. Today road freight accounts for around one-fifth of global oil demand. Growth in demand has outpaced all other sectors every year this century. And there are many ways to tackle the problem. Lightweighting is one. Better vehicle design is another. Driver training is a third. In all of these areas, we should be looking to find niches for Australian companies, not just to develop the technologies, but to pioneer the business models that get the technologies on to the roads.

I take a particular interest in the potential for hydrogen as a low-emissions fuel. I'm currently leading a small group reporting to energy ministers on the potential for hydrogen across the economy, both here in Australia and as an export industry. So it interests me that Toyota is currently trialling hydrogen B-doubles in California.

What is of particular interest is that Japanese companies are looking to Australia as a hydrogen supplier. There are projects underway across Australia, some making hydrogen from coal, and some using excess energy from solar and wind farms to make hydrogen from water. The intention is to send it to Japan, South Korea and other countries that are determined to reduce their carbon footprint but do not have the abundant scope for renewables that we enjoy in Australia. I call the export of hydrogen made from renewable electricity "shipping sunshine".

Now running trucks on Australian sunshine might or might not be commercially viable, but the commitment of nations like Japan is very clear. And if the world wants to buy Australian sunshine, by all means, let's cheer them on.

The opportunities in your industry are boundless. So thank you for opening my eyes to the successful story of trucking in Australia. You are doing a great job. Enjoy the conference. And forgive me for saying it, keep on trucking.

CHAPTER

07

Innovation

"Optimise the levers"

Chapter 7 | Innovation

Introduction

The trouble with innovation is that it is hard to measure, which is why the Innovation and Science Australia Prosperity through Innovation 2030 report recommended the development of new ways to measure innovation. Sometimes, innovation is simply not measured because it is in a service industry, such as food preparation and presentation. Sometimes, it is not measured because the innovation is in processes rather than products. I often mention the Australian iron ore industry as an example. It is stunningly innovative in its use of automation, artificial intelligence and process quality control, with the result that Australia has more than half of the global iron ore export market. But because the final product is iron ore – year after year, decade after decade – the industry doesn't help us to rise up the ladder in international innovation rankings.

The other difficulty with innovation is the popular belief that it will be increased through collaboration, whereas my personal experience is that it is driven by competition. As always, the truth is in between.

This series of speeches highlights a range of examples on a single theme – the opportunities for Australia in technological innovation. I have argued that Australia has the edge in some key areas. First, quality. When we aim high, with the best quality products backed by the best science, we can compete internationally. Second, research and science, where Australia has a strong base. Third, tech that takes advantage of our strengths, which means agriculture, food and gene technology, mining and automation technology, and energy and renewables technology. And fourth, regulation, where Australia has some of the most robust frameworks in the world.

37. Science Fiction for Leaders

September 7 2017 | Speech to the Cranlana Program in Melbourne

I've always loved science fiction. But I have very little interest in science fantasy. The latter makes stuff up. Magic. The former extrapolates from what we know today to a future in which the conceivable has become the actual. And the human protagonists act like, well, humans. In 1970, Alvin Toffler's Future Shock described a population shellshocked, shattered with stress and disorientation from change that came too fast. In the 50 years since, the pace of change has only accelerated, rendering Toffler's scenario all the more visceral. As technologies heap one on the other, sometimes feeling challenging or alarming, how do we stay on top of it, not only emotionally, but in the regulations, laws and ethical systems that regulate technology, and ensure it is targeted for good? We need future thinking that subjects our future to human guidance. The human capacity for imagining what is to come is immense, evident decades ahead of time in the science fiction literature, some of which is recapitulated in this speech. Human capacity to invent and adapt is impressive in the extreme. We should welcome the future not with blind optimism, but with the firm belief we can influence it for the better. I am optimistic.

In the year I graduated from high school, 1970, a man named Alvin Toffler took the world by storm with a bestselling book. These days, it's barely remembered. But back then, it was big. The cover was purple: Space Age purple. And the title was *Future Shock*.

Future shock, the vertigo of the victims of progress. All around him, Toffler saw them suffering, people for whom change was too fast, and adaptation too slow. They were stuck behind their times, strangers lost in the present, frightened, adrift and confused. All they knew was that they could never go home. Home was in the past. And the past was dead, gone. Future shock, the shellshock of time.

The image that springs to mind for me when I think of those future shocked people is the Mars One Project. You may have seen it in the media, and when it was first announced, way back in 2012, I was very excited. I'm not now. You'll see why.

PHOTO: John Feder

The idea is to establish a permanent human colony on Mars by 2035. Here's the deal. You sign up to be a colonist. You pay your application fee, which gets you into the queue. If you're lucky, your application letter might be read. If you're extra, extra lucky, you might get an interview, pass the medical clearance, sail through the Mars Settler Suitability Interview, and be named in the final four. You're strapped into a space capsule and taken on a seven-month voyage to Mars. When you land, if you haven't suffered permanent damage from cosmic radiation, or gone mad from claustrophobia, you take up residence in a life pod, 10 metres by 50 metres. Then you stay there for the rest of your natural life. Yes, until you die. The technology doesn't exist to bring you home. You're trapped on an alien planet for life.

Now that sounds bad, but according to Alvin Toffler, future shock might actually be worse. At least when you sign up for the one-way ticket to Mars, you're travelling as a volunteer. But the future never asks if you want to come along. The future doesn't test if you're ready and resilient. The future doesn't train you, prepare you, equip you. No, it just blows up your home planet and hurls you into space. On and on. Faster and faster. A stomach-churning and heart-sinking and gut-wrenching ride, for the rest of your life.

For just five seconds, hold that image in your mind. That's future shock.

Alvin Toffler wasn't kidding when he called it a disease. He meant it literally, something you could experience as a physical and psychological condition. Or as he put it, "the shattering stress and disorientation that we induce in individuals by subjecting them to too much change in too short a time".

And this was something he detected in 1970. 1970, years before personal computers, the internet, the smartphone. It's the age of Twiggy and the Beatles, when words like cloning still appear in Toffler's book in inverted commas, and the author has to apologise for the outlandish idea that maybe, just maybe, you could take a frozen embryo and choose a human surrogate and grow a baby.

Toffler expressed it like this, and I've updated the numbers for our time. Take the last 50,000 years of human existence, and divide it into approximately 800 lifetimes of 60 years, somewhere between the lifespan of an ancient and modern human. Of these 800 lifetimes, 650 were spent in caves. Only in the last 70 lifetimes have we known any form of writing.

Only in the last six lifetimes have we had the printing press. Only during the last three lifetimes has anyone, anywhere, ever used an electric motor. And almost everything material in your world today – every object, every technology, every building – was developed in the last lifetime. The 800th lifetime. Your lifetime.

It's no wonder that Alvin Toffler detected the symptoms of mass confusion and sheer exhaustion in the people around him. And he would undoubtedly concur with Jack Welsh, legendary leader of the corporate giant GE, and the author of the immortal line that now has the status of a law: "If the rate of change on the outside exceeds the rate of change on the inside, the end is near."

But Toffler detected something other than future shock in pockets of the population. A handful of men and women, not many, but a few, were racing to the future not as hostages, but as pilots and willing passengers. Some of them were actually signing up to build the rocket.

And in their minds was a vision of the future as a better place, which might be different and strange but is joyous at the same time, something that would be, for all humanity, a new home. They travelled with wonder, hope and conviction. They were proud to be human, and free.

> ***"We must begin by making speculation about the future respectable"***

And Toffler asked himself what it would take to make the journey to the future a voyage like that, not just for the few, but for the many.

Now I repeat, this was 1970, so Toffler had some unconventional ideas on how we might go about solving this conundrum. He was right when he predicted the gig economy, Instagram celebrities and a more embracing definition of marriage. He was wrong on colonising the oceans, human cloning and controlling the weather.

But buried in Toffler's book is a kernel that I take very seriously, not just as Australia's eighth Chief Scientist but as a lifelong optimist. An optimist with, yes, a genuine, bona fide ticket to space. I bought it from Richard Branson's space tourism venture, Virgin Galactic. Someday, I hope to be able to use it.

But back to Toffler and the Big Idea. Here he is, pondering on an incredibly powerful technology that he believes could ultimately save mankind from riots, chaos, war and civilisational collapse.

If the contemporary individual is going to have to cope with the equivalent of millennia of change, within the compressed span of a single lifetime, he must carry within his skull images of the future.

We must begin by making speculation about the future respectable.

Our children should be studying Arthur C Clarke, William Tenn, Robert Heinlein, Ray Bradbury and Robert Sheckley.

Not because these writers can tell them about rocket ships and time machines but, more importantly, because they can lead young minds through an imaginative exploration of the jungle of political, social, psychological and ethical issues that will confront these children as adults.

Science fiction should be required reading in the compulsory unit, Future 101.

That's Toffler's ultimate technology – the story. Imagination. Science fiction.

No, it's not what you expected to hear when you passed into the rarefied halls of the Cranlana Program tonight. But I hope to persuade you that science fiction is a respectable pursuit for leaders such as yourselves. And it's more than respectable. Leaders, future leaders, friends of future leaders, for you, science fiction is required. First, to help you understand the past. Second, to help you grasp the future. And third, to help you act in the here and now.

But first, there's a qualifier, and a caveat. The qualifier is that the science fiction in question has to be good. By good, I mean my definition of good, meaning that it has to pass two tests. One, it has scientific plausibility, in the sense that it builds on our existing technologies or is at least broadly consistent with our best understanding of the laws of physics. I call this the "no magic" rule. And two, it has narrative plausibility, in the sense that it strikes us as a fair representation of how human beings might actually behave. I call this the "human factor". No to magic, and yes to human.

I impose these tests not for reasons of snobbery or to suggest that you can't learn anything from books or films that don't meet the rules. Of course you can, but you're not engaged in what Toffler called "social futurism", and we might call "future thinking".

When writers or directors pass my tests – no to magic, yes to human – it confirms that they have actually sat down, taken their concepts and turned them over and over in their heads. They can tell you what their worlds would look like, taste like, smell like, feel like. And so they are forcing you to experience a possible way of being human. So that's the qualifier.

Now the caveat. Science fiction is not an alternative to learning science. No, I don't think you can toss away the textbook and screen *The Terminator*. You might use *The Terminator* to catch a student's attention and overcome the ridiculous divide in our minds between maths and English, between science and arts.

Let the kids who love English discover science in a film or a book! Let the kids who love science start thinking about society and culture through a story! Let them think, and dream, together. And make them all read piles of books. Just a thought.

"Let the kids who love English discover science in a film or a book!"

But of course, for any subject, it's not enough to simply catch the eye. The secret is capturing the heart. You need to have the passion to push through the drills and the tests, and keep going. That's the difference between entertainment and education. It's important. Let's respect it.

* * *

Now, let's begin. Textbooks open, welcome to Future 101. The first reason you need science fiction is to understand the journey from the past to the way you live today. You might not know it, but you live in a world imagined for you and scripted for you in science fiction.

For some of us, this is literally true. We call it Pokemon Go. But we could also point to the inhabitants of Second Life, a 3D virtual world where people meet, shop and trade by their avatars. You can trade Second Life money for real money. And you can study in Second Life towards a real degree. Universities have adopted the platform so that students on opposite sides of the world can work together in real-world problem scenarios.

The creator of Second Life was directly inspired by fiction – the Metaverse depicted in Neal Stephenson's 1992 novel *Snow Crash*. And, of course, Second Life has gone on to inspire later works of fiction.

One of the joys of reading the great novels of the past is to follow the weaving pattern of ideas like this, from fiction into fact and back into fiction – like two opposing mirrors, endlessly bouncing rays of light.

Perhaps some of the greatest examples of science fiction's impact on society are the ones we now consider boringly normal. The ubiquitous office scanner and photocopier was carefully described by Isaac Asimov in his *Space Ranger* book published in 1952, five years before the very first image scanner was invented. An electronic fingerprint scanner, like the one I use to unlock my iPhone, was used in the exact same book. Asimov also envisaged the use of a personal, portable computer in 1954, more than 20 years before the first clunky laptops hit the shelves in 1975.

Or take Orson Scott Card's *Ender's Game*, published in 1985. He envisaged a world where students used flat, touchscreen computers in class, where citizens could access the "nets" for worldwide digital communication, and where anyone could commentate on politics while hidden behind a digital identity. Today, we call these tablets, the internet and social media.

It's a reminder that every great human advance is preceded by a leap in imagination. If we learn nothing else from science fiction, that alone would make the effort worthwhile. So science fiction is essential to you as a student of history, looking to learn from the past.

The second reason you need to pay attention to science fiction is as a student of the future, looking to grasp the world ahead. Now I sense your anxiety, and I understand. We associate speculating about the future with prophecy – voodoo and astrology and economics. Did I say that? My apologies. Voodoo and astrology and magic.

As a leader, I agree that scepticism has merit. But like all things, in moderation. Too much scepticism simply blinds you to opportunity.

"The horse is here to stay but the automobile is only a novelty – a fad." That was the President of the Michigan Savings Bank advising Henry Ford's lawyer not to invest in the Ford Motor Company, back in 1903.

"Heavier-than-air flying machines are impossible." Lord Kelvin, President of the Royal Society of England, 1895. The Wright brothers proved him wrong just eight years later.

"There is no chance that the iPhone is going to get any significant market share. No chance." Steve Ballmer, CEO of Microsoft, 2007.

Yes, looking ahead, imagining change, carries some risk. But it is important. And any leader who ignores it is unworthy of the position. This is understood by leaders in government, in business and in science. It is why the Commonwealth Science Council was created, to combine insights from all three sectors into national policy development. Chaired by the Prime Minister, and with myself, as Chief Scientist, as the Executive Officer, the council has a mandate to position this country for the sort of future Australians want – prosperous, healthy, secure, prepared.

Acting on that mandate, we have commissioned a series of Horizon Scanning reports from the preeminent institutions that make up the Australian Council of Learned Academies. Four projects are well underway, on:

- Energy storage;
- Precision medicine and gene editing;
- Synthetic biology; and
- The Internet of Things

There are more topics to come. Every one of these topics represents a make or break moment for Australia. Capitalise on the opportunities and we won't just create jobs and wealth, we will literally add years to our lives. Miss the boat, and we will struggle to sustain the phenomenal economic growth streak that has only been possible because our predecessors had the vision to look ahead.

Now I am not suggesting for a moment that you can simply read the future in a science-fiction novel. Clearly, you can't, which is why we have the Commonwealth Science Council, the Learned Academies and the Horizon Scanning reports. But there's still an important place for imagination. Step back from the idea that science fiction is, or should be, a prediction. Think of it instead as a simulation, a way of testing possibilities and thinking through how we might respond.

Let me explain by way of an example, *The City and the Stars*, by Arthur C. Clarke, first published in 1956. The city is Diaspar, a completely self-contained society where people live forever. They are born into physical bodies that last for about 1000 years. At the end of that time they choose which memories to save, dissolve their bodies and return their brains to the central memory bank, to be born again, in a new body, in 100,000 years' time.

Everything they could possibly need or want is provided. They don't have to sleep, they don't have to work, they never get sick. How do they pass the time? They can step at will into any one of billions of scenarios, or Sagas – virtual worlds that they experience as real. When the story begins, they have lived this way for 1000 million years. So yes, it is a picture of success.

But it wasn't intended as a fairy tale. Not at all. Arthur C. Clarke was asking something difficult and profound. He was asking whether humans in a world that took care of their every need could still lead lives of real meaning and purpose, if they only experienced shock, or risk, or struggle in fantasy.

And isn't that the very question that every parent of a teenager with an X-Box and a Vitamin D deficiency is asking today? Can she really be happy, if she spends all her life in her room, playing those wretched video games? Can I ever persuade her to get a real life, with a real job, and real friends? Read Arthur C. Clarke, and prepare to think.

And that brings me to my final point, the crux of the issue for you as leaders of our society, trying to boldly go where no-one has gone before. How can science fiction help you to go beyond thinking and reflecting, to acting? To leading?

You know, as I know, that we will be confronted in the years ahead by technologies that challenge or alarm us. Babies with three genetic parents. Autonomous killing machines deployed as weapons of war. Companies that microchip their employees. That's today, here, now, for real. How are we to cope when the onrushing future crashes down on us, 100 times stronger, when the victims of future shock multiply, when the fear is so visceral and raw?

It seems to me, as it did to Alvin Toffler, that no question is more urgent, or more confounding. But let me answer in the only way I know how, as a techno-optimist, an engineer, a scientist, a serial entrepreneur, a husband to a woman who describes the future, and a father to two sons who help to bring it into existence. Someone who could not possibly be any more invested in the future than he is today. And an occasional reader of history and science fiction.

I start in the firm conviction that human beings can and do adjust to complicated and even dangerous technologies, given time. Look at the motor car. Look at electricity. Look at aviation. All of them were once seen as technologies far too dangerous to put in human hands, and yet we tamed them.

So we can and do harness our powers for good, like a child learning to pick up the sweet guinea pig and pat it nicely, without crushing it to death. But soon we're going to be a child with superpowers, a child who could crush civilisation in his fist before he ever gets the chance to grow wise. But also, a child with superpowers who could do amazing things.

PHOTO: Copyright unknown

We will always go wrong when we stumble down any one of three paths. One, utopianism. We buy into overblown promises far beyond anything that the science can actually support. On this path, we expose people to the harms of magical thinking. They start to think of science as the silver bullet. When they discover that the answers are never easy, that every technology has costs, they feel betrayed. And we panic and impose a total ban.

Two, dystopianism. We set out in the belief that the future is bound to be terrible and so we may as well stop trying. On this path, we don't bother to look down the technology pipeline or engage with science. We imagine that technology runs rampant, people are blindsided and the only possible future is bad. And we panic and impose a total ban.

Three, atavism. We tell ourselves that everything was good in the past, so we should go back there and do more of the same. Forever. On this path we don't just miss out on all the benefits of change. We discover that our image of the past was an illusion, impossible to recreate because it only ever existed in our minds. Meanwhile the modern problems, the real problems, don't go away. They spiral. And we discover, all too late, that we've turned our backs on the science that might have helped us to solve them. And darn it all, what's left to ban?

The only way to thread the needle between utopianism, dystopianism and atavism is to do our utmost to equip our society for critical and challenging debates.

And science fiction will help. Science fiction, which can engage large numbers of people in the collective mission of imagining the future. Science fiction, which carves out a space for the future in our minds. So that no-one is blindsided. So that people are challenged to think, and helped to be informed. So that we can calibrate public policy with a better sense of the sort of challenges we might be facing ahead.

Let me give you an example: self-driving cars. The very stuff of science fiction. And in their own way, very scary to many people. How do you ensure that in the moment when the self-driving car is approaching the intersection and the little old lady steps off the kerb and there's a baby in the car that the car will do the right thing and protect the little old lady and the baby from harm?

But what if a crash is inevitable? What should the car be programmed to do? Should I be able to choose the settings of my car, so that I can prioritise my life over everybody else's?

We can play this game for hours, and people do, through an online platform developed by MIT. It's called the Moral Machine. And it's designed to crowdsource the answers to precisely these sort of human dilemmas, not just to inform governments and technology developers, but to get people thinking and engaged.

Last month the German Government came up with an initial answer: regulations that require self-driving cars to place equal value on all human lives. The decision-making algorithms will not be permitted to discriminate on any grounds, not age, not gender, not race. All lives count the same. One human, one life, one rule.

Germany is getting ahead. It saw the looming thicket of moral and legal concerns, and it responded by clearing a path. So developers have clarity and direction. And communities know their values count, that the future is a place made not just for them, but by them. Other countries might configure the ground rules differently, but any wise leader would agree good regulation is a leader's best legacy.

Good science fiction prepares the ground for good regulation. And good regulation will guide us to the good society.

I began with the image of a society shattered by the velocity of change. Let me conclude with the image of a society exhilarated by the possibilities of progress. We are more capable and creative than we know. We hold the pen and we write the future. We can choose to be heroines and heroes. Set out in that spirit, and I promise you, our greatest adventure has barely begun. And our children will marvel when they come to read our chapter that we touched with our human minds, a distant tomorrow.

38. A Mind to Win

August 17 2016 | Keynote Address to the Australian Financial Review Innovation Summit

I'm often asked to speak about innovation, and I always find it a difficult brief. I think this is because speaking about innovation almost feels antithetical to actual innovation. It's easy to criticise organisations and governments for their lack of imagination, collaboration and international-scale thinking, but it is much harder to devise realistic solutions. This speech to the 2016 AFR Innovation Summit explores areas for improvement: investment in infrastructure, aiming high with our education, building a culture of self-belief, and playing to our strengths. I point out that America's giant tech companies didn't materalise out of some magic ingredient in the Californian soil, just as Silicon Valley isn't a byword for automatic success, and there is nothing that says world-leading innovation can't be owned by Australia. We have the capacity and the foundations. In this case, the innovation brief was easier than it might have been because having visited Iceland, I was able to draw valuable lessons from a most unlikely source: the Icelandic football team.

Appetite for success

It is a great pleasure to address this flagship innovation event in National Science Week. On Monday, I set out a challenge: by the end of the week, let's all know the names of at least five Australian scientists. Five living scientists. Not including me.

Put up your hand if you feel confident you can already pass the test. Leave your hand in the air if you feel confident for an attendant with a microphone to come by and give you the opportunity to demonstrate your knowledge to the rest of us here today. But not to worry. We all have until the end of the week to take the Five Scientist Pledge.

> *“I hope that we come here today with a mind to seek out success, and a willingness to embrace a share of risk”*

And I hope that we come here today with a mind to seek out success, and a willingness to embrace a share of risk. I like to think I set the pattern early. In my maiden speech at the National Press Club in March, I told the story of the Vasa, a 17th century Swedish warship. It was the pride of the nation. The most complicated war machine that the Swedes had ever built. An innovation project unlike any other. And it might have changed the course of history, if it hadn’t sunk with a puff of wind, 20 minutes on from the gala launch. It was about as seaworthy as a concrete duck.

I opened with that story and embraced my destiny as the first Chief Scientist to launch himself with a shipwreck. But I did it to make an important point about the attitude we take to innovation. Doing something new means facing the risk that you might fail. But doing something successfully means accepting the risk and proceeding with science, not just self-belief. It calls for big vision and a pragmatic path. One without the other is a glorious concrete duck, or the same old canoe you’ve been building for years.

So even a shipwreck can be very instructive. Still, I will be travelling to Europe very shortly. And it has been pointed out to me that the Vasa was my first and last reference to Scandinavian innovation. I wanted to take the opportunity to revisit the topic today.

And I am aware that another event is going on alongside National Science Week, and it has to be significant, because even the Financial Review has devoted a page or two to sport. So, combining the nation’s love of sport with my interest in Scandinavia, let me tell you the story of Iceland’s soccer team.

The Icelandic puffin that roared

If you’ve visited Iceland, you will know the weirdness of the Icelandic moonscape. I went there with my wife, son and daughter-in-law in January. The dead of winter. The sun doesn’t rise above the horizon and the thermometer is offended by positive numbers. Why, you might ask, did we go to Iceland in winter? To chase the northern lights, the aurora borealis, but that is another story.

We hired a Land Cruiser at the Reykjavik airport and drove through the late-morning darkness for an hour to get to our hotel. The landscape was flat and dotted with black basalt boulders capped with white snow hats. At the hotel, we piled out of the car to find that the door to reception was locked. As we huddled in the cold, with the vapour from a geothermal power station billowing on the horizon, surrounded by endless white-capped basalt boulders, my wife looked at me mournfully, shivered and said “I want to go back to Earth”.

This, ladies and gentlemen, is Iceland, home to 10 million puffins, 300,000 people, and now, the soccer team that knocked England out of the finals of Euro 2016. Of course, sport will always yield its share of random and inexplicable results. But Iceland’s success in soccer has been both significant and sustained. Over the past three years, Iceland has climbed 109 spots in the FIFA rankings.

PHOTO: Copyright unknown

Wouldn’t we be glad to move even one or two notches up the Global Innovation Index, or the OECD ranking for schools.

So let’s dig a little further into this Icelandic volcano. If it wasn’t stunning luck, how was this explosion of talent obtained? Simple. It was the choice that Iceland’s soccer fans made, way back in the 1990s, to be winners in 2016. They understood that they couldn’t win England’s way. They didn’t have A-grade soccer pitches; they had gravel. They didn’t have the star international players; they had weekend punters. They didn’t have sunlight in winter; they had darkness and gale-force winds. And under those conditions, no-one wants to train.

So how does a country with all those excuses for failure build a genuinely competitive soccer team? Four things.

Number one, they created the infrastructure. And the Icelandic innovation was the indoor football house. At a stroke, athletes who spent half the year inside could still train all year round. Soon local councils were competing to build these indoor pitches, with private capital and public money. And, of course, they could afford to heat them as a result of Iceland’s excellent and inexpensive geothermal power.

Number two, they invested in education. And they spent their money wisely, on training the trainers. They stopped relying on well-meaning parents and started paying for the training and accreditation of their coaches. For every 500 Icelanders, there is now one internationally accredited coach. And every child with the talent for soccer can pursue it with world-class support, including the support to be mentors and teachers in their turn.

Which feeds into number three. They built the culture. In the 1990s, it was said that you could hear a pin drop at an Iceland soccer game – if anyone were actually there to drop the pin. This year, close to 10% of the population travelled to France to watch the team at Euro 2016. It was almost mandatory to watch the games back home. Young people are signing up, sponsors are coming on board and soccer is fusing into daily life.

And finally, number four, they played to a strategy. With no star players, Iceland had to work out how to be a star team. And it turns out that small countries with a strong work ethic can win on discipline and organisation.

Perhaps a gene pool that skews towards tall, strong and athletic also helps. But they still needed a great game plan, and they needed to pursue it through a great leader. Iceland found that individual in the much-loved local dentist, who currently doubles up as the part-time head coach. Yes, as a dentist his core experience is pulling teeth, but what is leadership, if not the art of pulling teeth in a reassuring way? And this dentist sent the players out on to the pitch in good health, with a mind to win.

As one spokesman told the media: "When we go out on the field, we're not thinking, we'll try not to lose so bad. We're thinking, we're going to beat them." And surprise, surprise, come the big match, mighty England went down.

A vision for Australia

So what can we learn from the lessons of Iceland's success? Let's start with the attitude it takes to win. Any startup, or startup nation, needs to start with a bold aspiration, and it can't be "just lose small". We wouldn't accept that from our Olympic swimmers. And we wouldn't fund elite swimming as generously as we do if we thought the outcome would be, every now and again, a flash of bronze.

By the same token, a small goal for Australia will not attract all the fellow-travellers we need to achieve something that's ultimately worth having. We have to stop telling ourselves and everyone else that innovation only works in those magic lands like Silicon Valley. I can tell you as someone who's tried it, even in California, success comes very hard.

> *"It is a business of maximising the potential for people to perform, through a combination of smart regulation and strategic investment"*

Read the Los Angeles Times today, and you will discover any number of reasons for Californians to complain. Our rents are too high! Our tech stock is over-valued! And then we've got that presidential election in November, so we may as well move to Canada now! If the pundits are pessimistic in Los Angeles, well, you can bet that they're apocalyptic on Wall Street.

We might scoff and tell them to keep their problems in perspective. As of last week, the five largest companies by market capitalisation on the S&P 500 were all tech firms: Apple, Google, Microsoft, Amazon and Facebook. And all of those companies except Facebook spend more on R&D than the Government of Australia spends across the entire science and innovation portfolio. Let me repeat that. Individual companies outspend our national Government. What possible reason have Californians got to complain?

ut ladies and gentlemen, wouldn't they look at our universities, our banks, our stable regulatory systems, our cultural diversity, our proximity to Asia and our world-beating quality of life and wonder why we can't make a go of it here at home? Which is exactly what Vice President Joe Biden did last month, when he challenged Australia to be "the innovation hub of the Southern Hemisphere".

So no excuses for low expectations. We need to cease our self-criticism, because it only destroys our ability to build constructively on what we have. And we do need to build on that foundation, constructively, creatively and continuously.

Game plan for success

Now I am not pretending that we can achieve success by putting down all our big dreams in a policy document. You cannot order your country to have ideas or to pursue them, any more than you can order a soccer team to win. You can exhort, you can encourage, you can get creative with the salary cap, but ultimately, you need to build the capability to play the game consistently well.

The same is true in innovation policy. It is a business of maximising the potential for people to perform, through a combination of smart regulation and strategic investment.

And here, we can read straight from Iceland's playbook. Remember the key elements I outlined: infrastructure, education, culture and strategy. They map very neatly against the National Innovation and Science Agenda, as I know that Minister [for Industry, Innovation and Science Greg] Hunt will discuss tomorrow. I welcome the commitments that the Government has already made and, just as importantly, the impetus that is building behind this agenda.

But let me highlight a few elements of the national mission that will be central to my work, under those four headings.

First, the infrastructure. It's no secret. Great science needs great science equipment. And if science turns money into knowledge, then innovation turns that knowledge back into money, and generally a lot more money than the taxpayers put in. We have in Australia a very strong national research infrastructure base, which consistently delivers outstanding returns.

The Government and the research sector are enthusiastic to build the next-generation equipment on that foundation. Of course, ask 20 scientists, and you will get 56 opinions on what the taxpayer dollar should fund. My job in the months ahead is to collect those opinions, and condense them into a crystal, a 10-year National Research Infrastructure Roadmap. And I'll take some inspiration from Iceland in the drafting: build to the conditions, contain the operating costs, and maximise the use of the facilities all year round.

The next item on the list, education. Here we need to grasp that true Scandinavian insight, train the trainers. It worked in Iceland's football houses, and it worked in Finland's schools. I have said it many times, but in National Science Week it is important to say it again.

At all levels of education, from early childhood to PhD, we need to build in the incentives and support for quality teaching, as a national priority. We do have great teachers, but we should have what Finland has created, a great teaching system. And if Iceland can have one UEFA coach for every 500 people, we can certainly have at least one qualified mathematics and science teacher accessible to every child.

So, to the third item, culture. How do you change the way that people think? It's a question that plays on my mind every time I read another one of those articles about people with science PhDs who can't find jobs.

It irks me that people consider science PhDs to be excellent researchers, and nothing more. Surely, it shouldn't be so hard to think of other things that people with science PhDs are uniquely equipped to do. They are phenomenally hardworking. They are extremely bright. And they have to be both disciplined in their methods and creative in the way they apply them. If you want a worker who can solve a complex problem in a short period of time with resources strung out to the nth degree, hire someone with a science doctorate.

It just amazes me that more companies can't perceive it. I suspect it comes down to a lack of awareness and a lack of experience in harnessing a PhD's strengths. The only way to create that awareness is to give people the taste for success, so we have role models for people in PhD programs today, and advocates in the business community eager to bring those graduates on board in the future.

Commonwealth Science Council, 2016
PHOTO: Copyright unknown

So I will continue to investigate and advocate for two things: programs that bring down the threshold costs for business to engage PhDs both during after their training; and incentives for universities to introduce those programs.

Finally, to the strategy, the way we play to our strengths. And here I have the advantage of two team coaching roles, as Executive Officer of the Commonwealth Science Council and Deputy Chair of Innovation and Science Australia. In both roles, the basic task is the same: identify those areas where Australia has a national need or a strategic opportunity to pursue through science.

Bill Ferris has already spoken very ably for Innovation and Science Australia. On the Commonwealth Science Council, let me just say that I am looking forward to our next meeting with great relish. The council is our opportunity to bring together the captains of industry and academia with the leaders of government. The Prime Minister is the Chair, the Minister for Industry Innovation and Science is his Deputy, and the Minister for Health and the Minister for Education both bring their important perspectives as members.

The shared ambition is to inform the national game plan with foresight about the new challenges ahead, and insight about the strengths and weaknesses of the national team today.

And we will come with the inspiration of Iceland. You can come from a land of puffins and still have the spirit to roar. Let's make that the ethos of our gathering today.

I look around me at a room full of leaders, and people with the capacity to be leaders or to influence what leaders do. And I challenge each of you to use this forum to identify two things, two specific things, that you are going to take back to your organisation. Not 20 things that could conceivably be done if someone had a mind to pursue them. Two things that you are going to do because they will put your organisation on the path to opportunity.

You might start by looking up a few scientists' names, and taking contact details for their universities while you're about it. But finding potential in this country in easy. Explaining it, and acting on it, is the key. We have the chance to learn from experience today. So here's to the heroes of Iceland, and here's to a podium finish for the heroes at home.

39. If You Don't Look, You Don't See

September 19 2017 | Speech to the Australian Financial Review Innovation Summit

For Australia to capitalise maximally on its potential in innovative and new industries, we must first find a way to measure how we're doing. That's the only way we will know the things we are doing right and where we need to focus our effort. This might be an obvious statement, but the measuring is anything but. Nothing has frustrated me more in discussing innovation in Australia than the constant negative comparisons to other countries, based on flawed data sets and inappropriate comparisons. If you didn't know the country but took all the negative criticisms of Australia and created a fictional country that exhibited these characteristics, it would have suffered 30 years of falling GDP and most of its citizens would be living barely above the poverty line and in ignorance. The international comparators of innovation such as the Global Innovation Index tend to rank Australia relatively poorly, but they don't capture the world leading innovation in our mining industry; they don't capture hidden innovation such as the massive scaling up and branding success in our service industries; and they don't capture the international export success of our universities (albeit temporarily impacted by the pandemic). Certainly, we can do more in the digital space, where we have a good base. Crucially, we need to recognise Australians as great innovators and value that capacity; then we need to invest in it.

In the early days of GPS, a German man was driving his Mercedes Benz on a highway near Hamburg. And he was following the instructions on the screen to the letter. He drove past warning signs. He drove through barricades. He drove into a construction site, and he ploughed into a giant heap of sand.

Now we might laugh at that gentleman's blind obedience to a fallible system. A system, for the record, that comes with a very clear disclaimer: drive responsibly and disregard any hazardous or illegal suggestions. Prudent advice. But I want to put it to you that we might all be guilty of ignoring it. Not in navigation, but in innovation – the way we map it, the way we measure it and the way we discuss it.

I want to point out the genuine strengths of our economy, those that fall outside the range of the global innovation radar. And I want to persuade you that we have far more at stake than bragging rights in an academic debate. Our map of innovation is how we optimise the levers to steer our economy. Are we on the high road to progress or are we in the sand-heap of history? Either way, we ought to know.

Let me take you through the warning signs that prompted me to reconsider the map. When I became Chief Scientist it quickly became apparent to me that I was expected to do two things. One, talk at conferences on the dearth of startups and industry research engagement. And two, visit startups and launch industry research engagements. I seemed to be working for two different countries, the one that couldn't innovate, and the one that could. Of course, I was only collecting one pay cheque. But still, it seemed a little disingenuous.

"I seemed to be working for two different countries, the one that couldn't innovate, and the one that could"

Then I travelled overseas. Everywhere I went, people were asking me about the "Australian way". Look, they'd say, you've recorded an economic growth streak that has never been equalled by any other nation in the developed world. You're home to the most liveable city in the world, according to *The Economist* magazine, and three of your cities make the Top 10. Your universities are magnets for our students. Your healthcare system is one of the best in the world. Sure, your electricity isn't great, but let's move on. They'd ask me, what's Australia's secret?

Then I'd come home and no-one had ever heard of the Australian way. Look at the numbers, they'd say. We are bad at innovation, bad at invention. The implication back home was that Australia was the basket case of the OECD.

I didn't believe it. So I dug a bit deeper. I started asking people about the data. I asked people in business, people in universities, and people in government.

I discovered a strange phenomenon. Many people felt that the innovation metrics failed to account for their particular institution or industry. Or that the data were wrong for them but probably applicable to everyone else. I'd visit a vice-chancellor and their university was engaging with industry, at comparable rates to their partner institutions in the United States or Europe. Ergo, the problem was everyone else. I'd visit the CSIRO, and the message was the same. They were engaging with industry, the problem was everyone else. I'd visit ANSTO, and they were engaging with industry. Everyone was better than average. But, somehow, we were collectively subpar, like a class of geniuses that was incapable of passing basic maths. A conundrum.

Then I started working with Bill Ferris and the board of Innovation and Science Australia on indicators for the scorecard that we included in the performance review. We quickly realised that the attention-grabbing numbers, like our rank in the Global Innovation Index, were insufficient for the sort of monitoring and diagnosis we had in mind.

Guiding policy by that high-level ranking alone would be like navigating the streets in downtown Sydney using a low-resolution tourist map of Australia. What we needed was a suite of indicators that would be meaningful in the Australian context, but credible and perhaps transferrable to our partners overseas.

Given the time constraints, we built the best scorecard we could from the options available. It turns out that it is not easy to come up with indicators that are globally aligned, frequently reported and measuring causation rather than correlation. And many organisations were searching.

The Australian Academy of Technology and Engineering, better known as ATSE, ran a pilot study for a new measure of impact and engagement, which the Australian Research Council is now pursuing. Simultaneously, IP Australia was mining its databases to pinpoint the generators of patents. They found that, judging by the number of patents co-held by a university and an industry partner, our performance is similar to South Korea and Israel, and comfortably in the upper middle bracket of the OECD.

The National Survey of Research Commercialisation observed that Australian universities reported more than 10,000 research contracts, consultancies and collaborations in 2013. That figure is more than 10 times higher than the number of innovation-active Australian firms collaborating with research organisations that we reported to the OECD in the same year. And the survey figures did not even include the industry engagement by the CSIRO and other publicly funded non-university research institutions. Independent analysis by BHERT, the Business Higher Education Round Table, also questioned the OECD statistics on industry engagement.

There are other metrics which ought to raise an eyebrow. For example, we are rated 27th out of 27 OECD countries on the percentage of high-growth enterprises. That's terrible. But is it accurate? Does it make sense that a country that has sustained the longest economic growth streak in history has the lowest percentage of high-growth enterprises in the OECD?

Something is not right with the metrics. I freely acknowledge that there are innovation metrics that do pass the credibility test and indicate that there are regrettable gaps in our performance. That's a genuine concern. But we can't know where to intervene if we don't have a reliable and comprehensive picture. If you don't look, you don't see. If you don't see, you're driving blind.

So I thought to myself, what if I could use my position as a leader who speaks to leaders to collect instances of innovation not reflected in the metrics? And feed into a national effort to produce a better map? I've started by sorting my examples into four main categories, all of them important to our economy, but globally applicable.

First, embodied innovation. To start, think of two different successful companies. One operates a factory that makes silicon chips. The other operates a mine that extracts iron ore. Now be aware that one of the "knowledge diffusion" metrics in the Global Innovation Index is high-tech exports. This is a ratio derived from high-tech exports on the top line, divided by total exports on the bottom line, where high-tech exports are things like semiconductors, software, pharmaceuticals and medical devices.

The silicon-chip production advances a country up the Global Innovation Index because it contributes to the high-tech exports above the line. Of course, it also increases the total exports on the bottom line by the same amount, but the net effect is that the ratio improves. The iron-ore production, on the other hand, pushes a country down, because iron-ore exports only plug into the total exports figure below the line. That is, the more iron ore that is exported, the bigger the bottom line, while the top line stays constant, so the worse the country looks. Let me repeat that. The better we do at producing and selling iron ore, the worse we look. And yet an Australian iron-ore mine is arguably every bit as innovative as an overseas silicon-chip factory.

I think of Rio Tinto's Mine of the Future in Western Australia. I got a good taste of the extraordinary high-tech used by Rio Tinto when my wife and I visited the Perth control room last year. From there, they supervise their mine in the Pilbara 1,500 kilometres to the north. That mine includes the world's longest private railroad, much of it automated. The world's largest fleet of autonomous trucks. More than 400 operators in the Perth control room tracking 3D visualisations of every piece of capital equipment.

I struggle to imagine that even a silicon-chip factory could be working closer than that mine to the frontiers of artificial intelligence, big data, automation, materials engineering and industrial chemistry.

The mines operated by BHP and Fortescue are no slouches either. If our mining industry didn't invest in mining innovation, Australia would not be the iron-ore export powerhouse that it is today.

> ***"Too often, we see the rocks and not the robots, the products and not the processes, and so we discount the phenomenal effort and ingenuity required to maintain our competitive edge in primary industry"***

Now, if you know where to look, you can see the minerals sector in the existing innovation statistics. It is a major contributor to patent filings, research collaborations, technology investment and high-skill employment. But these are insufficient to describe the magnitude of the achievement and they don't scale with the production volume. Too often, we see the rocks and not the robots. The products and not the processes. And so we discount the phenomenal effort and ingenuity required to maintain our competitive edge in primary industry.

This suggests to me that there is something we should be counting, but instead we are ignoring. I couldn't even find a name for it, so I came up with one: embodied innovation. So first, let's measure embodied innovation. It's important.

Second, hidden innovation. I owe the unofficial name of this category to Bronte Adams, a colleague on the Innovation and Science Australia board. Bronte calls it the smashed avocado economy. Is it difficult to reduce an avocado to a green smear on a piece of bread? Not particularly. They do say that smashing it, as opposed to simply mashing it, takes genuine expertise. It's in the wrist action and adds about $10 to the price. But even so, where's the innovation?

Well, it's in the way we approach the avocado. A decade ago, avocados were good for two things, salad and guacamole. They were seasonal, the quality was variable, and for many people the price was exorbitant. So the industry set out to redefine the avocado as the all-round everything food. They reengineered the production chain to raise the quality, ensure supply and lower the price. At the same time, they transformed our awareness of what an avocado could be.

Now it's smashed avocado for breakfast, avocado smoothie for morning tea, avocado in sushi for lunch, avocado in tacos for dinner and, wait for it, avocado brownies for dessert. Avocado may well be the first solid food an Australian baby will eat. And the retail value of the Australian avocado industry has almost trebled in the past decade, from $340 million, to $920 million. That doesn't include the value added by countless cafes, and the way they've built the Aussie brunch into a global brand.

The Global Innovation Index counts creativity in terms of ICT exports, page edits to Wikipedia, YouTube uploads, number of feature films, and so on. It tries to lead you down the path to Silicon Valley. But Silicon Valley is just one of many places to visit. We shouldn't undervalue the innovation that smashed the avocado, simply because it is creativity in a different form. So first, we need to measure embodied innovation. And second, we need to measure hidden innovation.

Now third, social innovation. Let me illustrate this category by a story. A few years ago, Toyota was asked to assist a soup kitchen in New York. The company sent a team of engineers down to Harlem to watch the process and suggest improvements. With just three tweaks to the queuing system, the average wait time fell from an hour and a half to 18 minutes. If it happened in a factory, it would be called a process innovation, and measured in the Global Innovation Index and the OECD statistics. If it happened in a soup kitchen, did it happen at all? But did it improve people's lives? Absolutely.

Look at the innovation indexes. Where do they account for innovation that takes place outside the commercial realm, where the objectives are social, intellectual or environmental, rather than economic? So first, we need to measure embodied innovation; second, hidden innovation; third, social innovation.

And fourth and finally, incremental innovation. On a regular basis, I'm asked to name the big hitters in the innovation economy. To many people's surprise, I point to university vice-chancellors.

Our education export industry is a testament to their stunning capacity to steal a march. From the outset, they understood that their biggest asset was their reputation for quality. To build that reputation, they needed to invest in research. It is research that determines a university's position in the global rankings and hence its reputation.

Where might that investment come from? International students. And what attracts international students? The global rankings. And so the vice-chancellors created a virtuous circle, raising the quality of teaching and research, rising up the global rankings, and attracting international students. All the while welcoming more and more Australians into tertiary degrees. Between 2001 and 2016, the total number of students more than doubled, from about 600,000 places to 1.3 million places. That growth reflects a commitment to excellence, a capacity to adopt new technologies and a sophisticated grasp of the global market. Incremental innovation for spectacular growth.

So here's where I'm at – four tracts of uncharted territory that we need to map. One, embodied innovation; two, hidden innovation; three, social innovation; and four, incremental innovation. Four things that matter and ought to be counted.

But so what, you might say. Measures are imperfect. Move on. I can't move on. If our indicators aren't fit for purpose, if important chunks of our country are falling off the map, then we need to recalibrate. That's what my colleagues at ISA are seeking to do.

Call me old-fashioned, but I like to think that we go to the trouble of collecting data for a reason. We need it to inform our policy and help us to judge whether our interventions are making a difference. To our economy, innovation metrics and a strategic plan are like the dashboard and the GPS, respectively, in that Mercedes car I started with. Relying blindly on imperfect signals is no better than driving blind. It might even be worse.

To my surprise, I have come across some who say that it's better to undercount our performance than to overrate our success.

I disagree. Though I want to make it clear I am not for a moment suggesting that we don't need to improve. Of course we need to improve. We should always aim to do better. We should have bold aspirations linked to concrete measures, and measurable targets. On all the important measures, we ought to be aiming to sit comfortably in the top quartile of the OECD.

But what happens when we persistently sell ourselves short? First, we struggle to motivate ourselves to progress from our perceived abysmal position to merely very bad. Second, we dismiss the success of the programs that are actually working. And third, we might start to wonder, if our record is so dismal, and our economy is apparently thriving in spite of it, why bother with innovation policy at all?

To the contrary, we need metrics that give us an accurate picture of our economy to properly account for the critical role that innovation plays. Then we can work out how to leverage our strengths and address the gaps. Both deserve our attention.

Minister [for Industry, Innovation and Science Arthur] Sinodinos spoke this morning about the enormous untapped potential in the digital economy. I agree. Yet again, it's an area where we ought to aspire to sit comfortably in the top quartile of the OECD.

And who are the heavy lifters in industry with the resources to drive that ambition? When I last checked, our banks contributed more than half of the business R&D spend in ICT. Our mining sector funds some of the country's most innovative projects in artificial intelligence and big data. Our universities are global leaders in the provision of online services. And further, all of them – our banks, our miners and our universities – all of them are actively propagating as well as harvesting the intellectual potential that sprouts as digital startups.

Could we nurture that potential more effectively? Of course we could, if we start by measuring it. And follow up with strategy to provide a more compelling economic framework in which the sprouts can thrive. As Bill Ferris flagged this morning, watch this space.

But beyond Innovation and Science Australia, beyond public policy, beyond government, we need something else: a culture of striving, a culture of innovation, a collective belief that innovation is the essence of the Australian way. We need to stop berating ourselves for what we do poorly and take collective responsibility for building the success we want to see.

So my challenge to you is to look for the hidden potential. And start right now, by looking around you at the audience here today. Look at the calibre of the speakers on the programme.

Think about all the innovators you know, born in Australia, schooled in Australia, mentored in Australia. Think of all the people you respect who chose to come to this country, who spun the globe, with every option open, and chose to make this their home. Something worked. They came, they stayed, they thrived. Born in Australia. Migrated to Australia. Together, we are potential writ large.

And we're driving on the high road to tomorrow. With our eyes on the horizon, our innovation scorecard as our dashboard and our upcoming strategy as our GPS. Skirting the barricades, avoiding the sandpit and arriving at the destination of our own choosing.

40. Australian Innovation Business Dinner

April 27 2017 | 4th Australian Innovation Business Dinner in Munich as the head of the Australian Innovation Delegation to Europe

It's a challenge to give a dinner speech to a mixed audience of business people, diplomats and academics from two different countries. This speech, delivered in Munich, covered the field with a single story, about an incredible German immigrant to Australia who was so prolific in his research, advocacy and public good that I referred to him as a formidably intelligent, German-born, Australian-made machine. Australia's reputation and its global future is built on quality. This is where Australia has an edge and it is what must guide innovation in this country. This speech highlights two areas where Australian researchers and businesses have carved out a market in Germany, a powerhouse of industrial quality. The CSIRO's gluten-free barley now supplies a German beer-maker; and Melbourne firm Carbon Revolution has created a one-piece carbon-fibre wheel for the leading German car brands, Audi, BMW and Porsche.

I've noticed over the years that when we Australians think about Germany, we're usually thinking about two things, beer and cars. And I promise I'll get around to them in my speech. But first, let me take a detour back in time.

I want to take you back exactly 170 years, to 1847, when a young German scientist named Ferdinand Jacob Heinrich Mueller decided to come to Australia. And being German, of course the young Ferdinand Jacob Heinrich had come to work. In six years, he was named the inaugural Official Botanist for Victoria. In eight years, he had travelled 8,000 kilometres through the Great Sandy Desert, observing 800 new species along the way. In 10 years, he'd become the director of Melbourne's Royal Botanical Gardens. And in 20 years he'd been kicked off the board. Why? Because he opposed all the tourists and fountains and picnics cluttering up the park. They got in the way of his experiments. Ach du meine Güte, who thought gardens were supposed to be fun?

And who has time for fun? Certainly not Ferdinand Jacob Heinrich Mueller. No, he spent the next four decades writing 3000 letters a year, publishing more than 800 papers, serving on the first Australian Antarctic Exploration Committee, founding the Royal Society of Victoria, lecturing at every opportunity. And ended up, at a ripe old age, a hereditary baron and Knight of the British crown.

So stupendous was Mueller's output that, for much of the 19th century, he basically was our scientific partnership with Europe, a German-born, Australian-made machine. And he left his mark, as you can tell from the two mountain ranges, four individual mountains, two creeks and a river that Australians named in his honour. All that, plus a species of legless lizards. A baronetcy can't compare.

> ***"Mueller rocketed down the autobahn of life, but never out of control; he travelled instead like a classic German car, with supreme efficiency"***

So, clearly a great man, but why tell his story tonight? To me, Mueller is Australia's model of the very modern German: formidably intelligent, endlessly curious and phenomenally hard to slow down. He rocketed down the autobahn of life, but never out of control. He travelled instead like a classic German car, with supreme efficiency. He pledged his adopted country to the very highest standards, putting scientific rigour and professional reputation above the whims of fashion.

That legacy endures today, in the Australia he helped to bring about, an Australia that lives and dies by its quality brand. We succeed in the global market when we jump the high bar, with science on our side, whether it's the quality degrees on offer from Australian universities, or quality Australian baby formula and beef, or quality Australian clinical trials. The opportunities stem from knowledge, ideas and skills. Even those exports that are usually placed in the category of raw materials, such as minerals like iron ore, or agricultural commodities like wheat, represent astonishingly sophisticated knowledge chains.

You only have to visit Rio Tinto's Mine of the Future in the Western Australian desert to know that our export success derives from innovation. There you will see the world's most sophisticated fleet of self-driving trucks and the world's largest private railway, all managed remotely from an operations centre more than 1000 kilometres away in Perth.

A mining boom takes more than just raw luck. It's got to be luck translated. So we have learned a great deal from the determined German way and it is very much in our interests to invest in the relationship today.

Which brings me, as I promised, to great beer and fast cars. Good in moderation, and not combined.

First, to beer. In the year 1487, the duchy of Munich set the standard for what a beer ought to be: made from nothing but water, barley, yeast and hops. For 500 years, it resisted the temptation to water down that standard or compromise the reputation attached. It remains the definition of authentic German beer.

From left: PIK Director Hans Joachim Schellnhuber, the Australian Ambassador Lynette Wood, Dr Alan Finkel
PHOTO: PIK

But for beer-lovers who can't have gluten, that's a problem. Barley contains gluten. Beer must have barley. Ergo beer can never be gluten-free. Enter Australia's CSIRO, our flagship public agency for industry-focused research. Amongst its many strengths is agricultural science, including a decades-old program in wheat and grains. Harnessing that strength, CSIRO bred a strain of barley with 10,000 times less gluten than the standard variety.

Beer made from that barley can legally be marketed in Germany as gluten-free. And in February this year, the first commercial shipment of CSIRO barley grain left Australia, ready to be transformed into German beer. CSIRO, with its German partner Radeberger, leapt the high bars no-one else could jump. And so, an opportunity for Australian farmers was made.

Now, to cars. In my home state of Victoria, there's a company called Carbon Revolution. It makes the world's best wheels for world-class German cars: Audis, BMWs, Porsches. These wheels aren't just half as light as standard aluminium wheels. They're stronger and they reduce road noise.

The secret lies in the carbon-fibre technology. There are plenty of firms with capacity in carbon composites, but not many with the facilities to take a product all the way from basic research to production. That capacity enabled Carbon Revolution to design, test and scale the world's only one-piece, carbon-fibre wheel.

They saw their market was global from the start. That's why they reached out, when little more than a startup, to conduct the early laboratory testing in Europe. Make a wheel that's up to the standard for German cars, and you have a product fit to take on the world. And the company's motto is fittingly German: "Performance is everything. Efficiency is everything else."

So here's to the determined Germans. Here's to modern beer that complies with the ancient laws. Here's to fast cars that handle corners with supreme control. And most of all, here's to our joint venture in the great business of getting things done. Vielen Dank, thank you, and goodnight.

41. Science for Regional Australia in the Third Millennium

October 10 2016 | Public lecture on Science for Regional Australia in the Third Millennium, at the Charles Sturt University campus in Orange, NSW

It was irresistible. Give a speech in Orange, famous for its grapes, and talk about carrots. But as it happens, the story of carrots is the story of technological progress, built on human ingenuity. As reflected in the oft tweeted phrase from me: "I'm optimistic because I believe that human ingenuity is in unlimited supply." For Australia, becoming a global technology leader doesn't mean we have to build an iPhone. We are perfectly positioned to take the high ground in ag-tech – think, for example, of inventions such as the "Ladybird", a precision robot that identifies weeds in a crop and kills them, eliminating the need for generalised spraying, or the WeedSeeker, which does the same job at high speed in a bare field. By 2050 there will be about 2.4 billion more people on Earth and the overall population will be wealthier, leading to the need to increase food production by 60% to 70%. Investment in agricultural technologies is booming and the opportunities are huge. That's not the only industry where Australia can take the inside running. Transport automation is another, already used at scale in the mining industry. And the energy sector represents massive opportunity, including in renewables such as wind and solar, in battery storage and in hydrogen. Orange is a regional centre well-positioned to capitalise on these emerging high-tech industries.

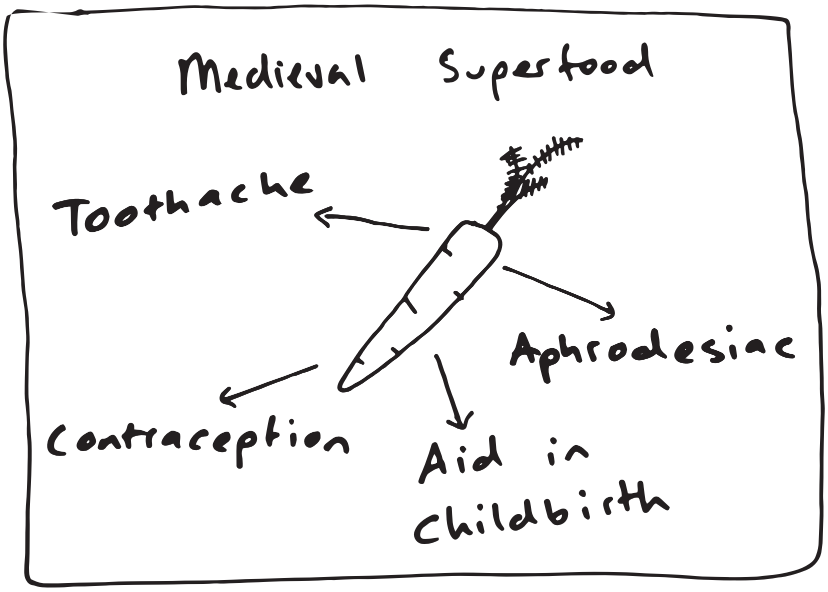
Unearthing the story of the carrot

I have to start with a confession. When I saw that I was coming to Orange, my first thought was "carrots". Because we all know that orange is the normal and natural way for carrots to be, don't we?

But I'm a scientist by training. In other words, I'm like a little kid! I want to know why all the carrots are orange. And I won't eat my vegetables until I get a proper answer!

Sometimes small questions can be the start of great science careers. And it often pays to do a bit of digging. Dig into the story of carrots, for example, and you have the story of civilisation, right there on your plate.

It begins 5,000 years ago, just as we were entering the Bronze Age. We have evidence of wild carrot seeds from that time in human campsites. We don't know exactly what our ancestors were doing with them because the carrots they pulled from the wild weren't orange but white. They weren't sweet; they were terribly bitter. Those wild carrots were thin, woody sticks with a pungent smell. So if our children think it's a punishment to eat their vegetables just think what it was like for the children of Europe 3,000 BC.



About 4,000 years later, in medieval times, cultivated carrots appeared in Central Asia. They were purple, some were pale yellow. They were, at least, decent for eating, as well as comparatively easy to grow. But they still looked a lot like parsnips, so much so that medieval scholars rarely bothered to tell them apart. Those scholars also decided that carrots boiled down with pepper worked as an excellent remedy for toothache, as well as an aphrodisiac, a contraceptive and an aid for women in childbirth. A medieval superfood, as it were.

In any event, it wasn't until the 1600s that the carrot really hit its stride, when the Dutch successfully bred an orange mutation, and made Holland the centre of a global carrot boom.

Why did the Dutch come to the view that orange was the best carrot colour? Some think it was a sign of loyalty to William of Orange and the movement for Dutch independence. Some think that all those Dutch still life artists were sick of dull colours and just wanted something orange in the bowl for a change. Some think that Dutch housewives hated the way that purple carrots stained their plates. Whatever the truth, orange was the colour that boomed, and it's lucky for us that it did. Today we know that the orange colour comes from beta-carotene, which is converted by the human body into vitamin A.

> *"Then we discovered science, and with science we rediscovered the world"*

And the timing was fortuitous. With the 18th century came the dawn of the Enlightenment and the scientific method. For thousands of years, we had fumbled our way in the dark, making the best of the wild cultivars we found, and learning through bitter experience how to farm them better.

But then we discovered science, and with science, we rediscovered the world. With science, technology and innovation, we had a phenomenal capacity to recreate it. And with science, technology, innovation and society, we have the carrot cake. And yes, we can eat it too.

Dr Finkel at Charles Sturt University, Orange, 2016
PHOTO: Charles Sturt University

Over the past 40 years, global carrot consumption has quadrupled, and the carrots we buy today have 50% more carotene than those of my childhood. Now carrots are turning full circle and going purple and knobbly again – because we are fickle consumers, with time to waste on turning food into Instagram art.

So the answer to “why are carrots orange?” is “because human beings made them that way”. And the answer to “what’s next?” is increasingly “what do you want?”

From carrots to CRISPR

True of carrots, and true of all the things we take for granted in our world today, all of them shaped by human ingenuity. It’s a reminder that change touches every part of our lives. And it’s a lesson in the way that societies like ours can come to accept and then embrace that change over time.

I have a theory about human beings. I think that we respond much better to carrots than we do to sticks. Not surprisingly, my theory is not unique. The legendary American architect and designer Buckminster Fuller, famous as the inventor of the geodesic dome, said it well: “You never change things by fighting the existing reality. To change something, build a new model that makes the existing model obsolete.” So don’t berate me for eating white and woody sticks of carrot. Instead serve me sweet and juicy orange carrots, and preferably in the form of a cake.

We need to see and taste the benefits of change to look to the future with hungry eyes. And we have already taken that path with so many technologies we now accept as a normal, even an essential part of life – from electricity, to vaccination, to IVF. Once, they were unthinkable. Today, we elevate them to the status of human rights.

And that is my point of entry to the important conversations about the future that we need to have today, be it babies with the DNA of three parents, or artificial intelligence, or nuclear power. Of course, those conversations have to play out at the highest levels of government across the world. But they ought to play out around the dinner table as well. After all, you can see the fingerprints of incredible change, right there on the plate.

And talking about the plate, let’s get back to carrots and the rich farm lands of the Central West that have been producing wonderful quality vegetables for so many years.

The way we farm is changing, and precision is the watchword. Pesticides are a useful tool in agriculture. But bulk spraying a whole crop or field is a waste, overdosing pest-free plants and contributing to excessive run off. At the same time, the number of labour hours required to manually check and spray each plant in your crop as needed comes at an equally enormous cost. So how do you save money, save time, and reduce the risk of chemical resistance?

Australian scientists have come up with a solution, a field robot called the Ladybird. This hi-tech piece of machinery is named after the common Ladybird beetle of childhood stories and songs. It has an outer shell painted bright red that is adorned with black solar panels. As it roams through the fields, the Ladybird computer brain has eyes to detect weeds, and insect-like robotic arms that extend and spray invasive plant predators.

Precision spraying systems are also in use for weed control on bare ground thanks to another Australian invention, WeedSeeker. This device has a high-tech detection system that identifies every weed then triggers a fast-fire valve to deliver a killer blast. And it can do this racing through the field at 25 kilometres an hour.

Precision agricultural equipment like this is a win-win, delivering lower costs for the farmer and lowering the impact on the environment by reducing the harmful run-off into our rivers and waterways. In North Queensland such technology might help preserve the Great Barrier Reef from devastating run-offs from the sugar cane farms that pollute the water and endanger the coral.

But it’s not just the farms. It’s the carrots themselves that are advancing rapidly. In May this year, the full gene sequence of the carrot was published for the first time. The researchers identified more than 32,000 genes in the typical carrot, allowing us to trace the evolutionary path back past the white carrot to the age of the dinosaurs.

By the way, you might think that 32,000 genes is not sufficient to define the life cycle of something as complex as a carrot, but incredibly it is 12,000 genes more than a human being. Later, during the question and answer session, I might be able to elaborate on why we humans are more sophisticated than a carrot. But I digress.

Once the gene sequence of a carrot or other plant has been determined, it becomes possible to manipulate it with a powerful new tool called CRISPR. Remember the term, because all the evidence suggests it is one of the technologies that will define our times.

CRISPR is not genetic modification as people have imagined it since the 1980s. This is something fundamentally different. CRISPR is like a pair of scissors that we can wield with nuance, efficiency and control. It’s highly responsive. We just need to know the gene we want to target.

This opens a world of possibilities. Perhaps we could modify the carrot to boost its pest-resistance or shelf-life. Or perhaps we could take some of the useful properties of carrots, like beta-carotene, and use that knowledge with other plants to tackle the problem of Vitamin A deficiency.

But the upshot is the same. With technologies like CRISPR, the question ceases to be simply, can we do this? And becomes instead, should we exercise this power? In many ways, the second is far more complicated than the first.

And to highlight this point, last week I had the privilege of being in Europe to speak at conferences in the Austrian capital, Vienna, and in the Belgium capital, Brussels, which is also the home of the European Parliament. In Brussels, I spoke at the same conference as the European Union Minister for Education, Tibor Navracsics. He assured the audience that the European Ministers truly listen to the explanations from their scientific advisors on the benefits and associated risks of existing and pending science and technology. But he urged us to accept the constraints of democracy. Ultimately, people's values take precedence over scientific evidence.

Embrace the carrot

Having said that, advances in technology never cease. As I see it, we can respond in three possible ways.

One, we can try to resist change – and those who choose that path are welcome to continue eating their nasty, bitter, white carrots.

Two, we can naively hope that all advances will turn out for the best – and those who choose that path are welcome to all the consequences that they refuse to consider in advance.

Which leaves only response number three: work out how science can be channelled to optimally serve society's goals.

Think, for example, of the changes currently remaking agricultural regions, and what that means for Orange and its surrounding regions. There are remarkable opportunities, but how do we seize them? We know there is a global need for more and better food. By 2050 there will be about 2.4 billion more people on earth. They will need 60 to 70% more food than what's currently available.

And what about the agriculture money trail? We know that food and agribusiness form a US $5 trillion global industry. The global venture capital invested in agricultural technologies topped US $2.3 billion in 2014. In 2015, it doubled to US $4.6 billion. The growth is phenomenal. For Australia, the opportunities in agriculture have never been higher. We can gain from the triple benefit of boosting yield, boosting return and creating a stronger and more vibrant ag-tech sector.

We see the massive contributions of technology in other sectors, too. In the energy sector, we have solar energy and wind farms. We already have cars powered by electricity driving on our roads – and I drive one. Future opportunities include lithium mining, natural gas exports, battery storage and hydrogen storage.

We've also seen technology contribute greatly to Australia's mining sector. This sector is highly innovative. Our big mining companies control driverless monster trucks, and the biggest train systems in the world are managed from control rooms in Perth. This automation and semi-automation improves product quality, improves efficiency and reduces environmental impact. We are exporting much of this inventiveness and technological knowhow to the rest of the world.

Mining, of course, is a big part of your local community, with the Newcrest Cadia Valley gold and copper mine just 25 kilometres from town.

Peeling the carrot

So why do we keep hearing from our public commentators that innovation is something that only happens in Israel or Silicon Valley, when it is everywhere? I don't know. But it's a perception I want to change. Encouragingly, when I replace the word innovation with "ingenuity" people realise that it is happening extensively around us every day.

The innovation economy is not just the university that develops a fantastic new battery, or the startup that forms to manufacture it. It is also the business person who works out how to make a profit as a distributor. It is the early adopter who works out how to use the battery to cut costs. It is the local council that gets in early and sorts out the regulations. It is the exporter who sees a way to sell the new battery technology to other countries.

Our innovation economy is what attracted the global aeroplane manufacturer Boeing Corporation to Australia, and now 3,000 of its employees work here, making Australia home to the largest Boeing workforce outside the USA. Boeing has a highly collaborative approach to research and development. By partnering with research institutes here in Australia, the innovative work carried out on our doorstep is having a profoundly positive impact on its global operations.

At every point in the supply chain, there are opportunities for people with imagination to follow a novel path. Some of them will have a so-called STEM degree – science, technology, engineering and mathematics. But many of them will be law graduates. They will be economists, teachers, nurses, town planners, winemakers and farmers.

There is no single model of the modern worker, simply a shared determination to be the architect of your own success. To take my own story, I founded a company in California in 1983. Fifteen years later, we saw an opportunity to dramatically expand from being a manufacturer of equipment for brain research to also become a manufacturer of equipment for genetics research.

This was a moment of opportunity but it was also very confronting. We were entering unknown territory. I remember going to lunch with my four key managers and over that meal our thoughts crystallised. We went back to the office and I gathered all the company employees. I informed them that the company had a new direction. Equipment for genetic research would be our new number one priority. Everything else would be number two.

This focussed approach led to product development in record time. The key driver of success was having the right attitude, from the top down. Everybody in the company was working towards the same clearly defined target and creatively used technology and innovation to achieve the goal.

Since then, I have reflected on what makes an innovative organisation successful. I have come up with my own four-point formula:

1. leadership commitment
2. effective regulations
3. human capital
4. financial capital

Main street of Orange, NSW
PHOTO: Jessica Wright

Starting with leadership commitment, the challenge is to keep the bar high, and then support the troops to deliver. It is about driving a culture of success, of relentlessly questioning what we have and wanting to do better. There is always a better way to do things.

On to the second ingredient. Effective regulations exist for two purposes. First, to protect the public. Second to facilitate commerce. They are both crucially important, and any perceived conflict between them can be resolved if there is determination to do so.

The third ingredient is human capital. There is no greater asset than committed, skilled people. They are the lifeblood of any organisation.

And the fourth ingredient for success is financial capital. I mean this in the broadest sense. It could be a loan, a government grant or a concession. Financing must be generous for innovation to flourish.

And everything's coming up Orange

Do we find these four ingredients for success here in Orange? On the evidence I've seen today, I believe we do. Especially in consideration of human capital. It is always refreshing to see a university that understands how important science is for the future.

What strikes me is the decision by Charles Sturt University to make Orange campus a centre for excellence through specialisation, with the focus on science and health courses, including dental science, pharmacy and physiotherapy.

I am sure that here on the Orange campus, we are training the scientists and health professionals of the future. And because they have trained in regional Australia, the data shows that they are more likely to stay in the regions and benefit our regional cities and rural areas.

It seems that in Orange you are building a bright future based on a respect and understanding of your past. This campus is built on the foundation of the Orange Agricultural College that was established in 1973, and is in the process of being transformed. I am impressed by the training laboratories and research facilities here at the campus and by the knowledge and enthusiasm of both students and staff whom I met today. The university is also embracing online learning and collapsing the barriers of distance.

There is much to be proud of in Orange and the surrounding region, with your reputation for boutique food and wine drawing in tourists from afar. On my drive from Canberra today, I saw green countryside bursting with life and energy, and adorned with the wind farms that will help to preserve that beauty for our grandchildren. Here in Orange, I have been struck by the magnificent historic buildings explicitly preserved for all to enjoy. Orange is preserving the past while creating a bright future.

To conclude, I want to challenge you to think about how science shapes the way you live and your quality of life.

Technology is often accompanied by side effects, such as pollution, but with time, variations are developed that eliminate the side effects so that we can enjoy the benefits guilt-free. With technology, we can continue to enjoy sustainable, productive agricultural landscapes that coexist with pristine rivers.

Let me close with a tribute to Israel's former President, Shimon Peres, who passed away two weeks ago. I heard this in Brussels from the European Minister for Science, Carlos Moedas. Shimon Peres was a visionary who knew the importance of science and innovation to building a community, and building a country. He said, "There is no way to escape poverty without science; there is no way to achieve peace without science." It is a message from the other side of the world that applies equally to us gathered here tonight in this lecture hall.

With science and innovation, we can shape the future and put ourselves on a path to greater prosperity.

42. Shooting the Rapids

February 3 2016 | Speech at the Trans-Tasman Dinner at the Australian High Commission in Wellington

New Zealand has monetised its mountains to turn the country into a top destination for adventure sports, capitalising on its dramatic natural environment and entrepreneurial spirit. Australia has its own runs on the board, with its world-learning innovations in banking, mining and international education. But both counties would benefit from working more closely together, sharing their research base, sharing their expertise in entrepreneurship and innovation, and harmonising their regulations to ensure a free flow of ideas and products. This speech, delivered to an Australian and New Zealand business audience in Wellington, reflected on my numerous, adrenalin-filled vacations with friends and family in New Zealand.

Speaker of Parliament the Right Honourable David Carter; Deputy Prime Minister the Honourable Bill English, and Ministers of the Crown; Members of the NZ Parliament; Australian High Commissioner His Excellency Peter Woolcott, Heads of Mission, and Members of the Diplomatic Corps; Former Prime Minister the Right Honourable Jim Bolger; Chief Science Advisor Professor Sir Peter Gluckman; ladies and gentlemen.

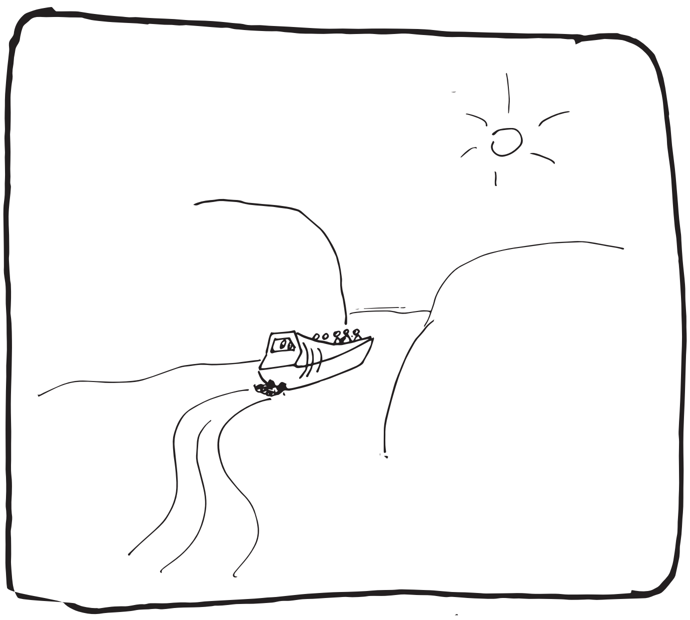
I was thinking about what I'd say this evening, and I realise I'm in a bit of a bind. Innovation. It's a great topic, and I'm all for it. But these days, so is everyone. A talk about innovation is no longer an innovative talk. So I'm going with the reliable primary school fall-back option instead: What I Did On My Holidays. Bear with me here. There's no slide show, but I promise there is a point.

I've done so many incredible things as a tourist in New Zealand:

- jet-boating
- helicopter skiing
- helicopter beach landings
- mountain trekking
- aeroplane landings on glaciers
- skiing on glaciers
- travelling at 4 g upside down and round and round as a passenger in a stunt plane
- piloting a Czechoslovakian jet fighter through a barrel roll over Lake Wakatipu
- and flying an aerial torpedo suspended by a steel wire from three mountain tops

But not bungee jumping – now that would be dangerous.

I've done none of these things in Australia, and I'm not sure if there are places where you can. But when I'm in New Zealand I can't wait to give them a go. You might contend that I am risk-inclined, but on this one, I'm just following the trend. People come here as tourists but they go home as adventurers. You convince them to leap off bridges, and you get them to pay. Now I respect that. And I think we can take some lessons about innovation.



After all, what is innovation but a leap into the unknown? And what is the innovation agenda about, if not turning those bold leaps into the core business of the entire country? We can't just kick people off bridges. Instead, we've got to persuade them that the risks are manageable because the supporting framework is sound. And I'd say that comes down to four things that the adventure sports industry can teach us.

First, we need to harness our natural advantages. Like mountains. You've got lots of them. They were useful in many ways before adventure sports. But then you monetised them in a whole new way.

Second, we need science, and plenty of it. If I'm flying an aerial torpedo between the mountain tops I want to know the steel wire is strong. By the same token, as an investor I want to know that the country's science capability is strong.

Third, we need innovation to turn science into products. What looks like falling off a cliff to me can be a few magic seconds of flight to you. The difference isn't the canyon, but the capacity to envisage a high-strength steel wire. Then to manufacture the experience – at scale.

And fourth, we need to get the regulatory frameworks right. Pull the seatbelt in the jet boat too tight, or too loose, and you'll regret it. Get it right, and enjoy the ride. Good regulation gives companies and people the environment in which they can operate confidently to achieve great things.

Now it's very clear to me from my conversations today that both our nations are firmly committed to innovation. The Australian Government made its most recent commitment, last December, through the release of the National Innovation and Science Agenda. At the time, the New Zealand Science and Innovation Minister, Steven Joyce, suggested that we'd just cribbed the best bits from New Zealand.

> ***"It's time to strap on our seatbelts; we're flying into the future"***

So it's like pavlova – a good thing for which we can all take credit. And we both have some impressive runs on the board.

For New Zealand, it's agriculture, tourism and a growing IT industry. For Australia, it's banking, mining and international education.

But we can do more, and we want to do more, individually and together. By collaborating on some of our research strengths and future research infrastructure. By sharing approaches to entrepreneurship and innovation investment. By regulatory arrangements that make it practical for new products to get a free guernsey in each other's markets.

I'm delighted that tomorrow I will meet with Prime Minister John Key, today I met with Minister for Science and Innovation Steven Joyce, and throughout my two-day visit I am working closely with your chief science advisor, Sir Peter Gluckman. In my role as Australia's Chief Scientist I have a broad mandate, advising government across the spectrum, from primary school education, to innovation strategies.

There's a lot happening on both sides of the Tasman. It's time to strap on our seatbelts; we're flying into the future. The aeroplane is a good one, but there's no time like the present to be working on the next design – longer range, lower operating costs and a better return on investment.

CHAPTER

08

The X Factor

"Too good to leave out"

Chapter 8 | The X Factor

Introduction

As I write these words, sitting in my office in suburban Melbourne, four tourist-carrying hot air balloons are drifting past my window, close enough to touch with a stick. They are symbolic of what makes humans what we are – a species that conquers gravity with lighter than air vessels and sees deep into space to the beginning of time with gravitational wave detectors and radio telescopes. And, as it happens, those floating balloons are also exuberant celebrations of our emergence from the great 2020 COVID-19 lockdown.

This chapter is about the X Factor, the magic ingredient that drives the great leaps forward, such as detecting gravitational waves.

43. Visions of Victoria

August 28 2017 | Annual La Trobe Lecture in Melbourne as the 2016 Victorian of the Year

When I was named Victorian of the Year in 2016, as well as a plaque, I was given a cutting from a descendant of the Separation Tree under whose shade in the Royal Botanic Gardens the citizens of Melbourne gathered to celebrate the separation of Victoria from New South Wales, formally proclaimed in 1851. I donated the cutting to Monash University, where it is happily growing in a prominent location. The year 1851 was not just the year that my home state was proclaimed, it was also the year in which the Crystal Palace exhibition in London's Hyde Park opened. The exhibition was a stunning showcase of invention, futuristic vision and superb pieces from exotic locations – a grand statement of the things that people can make. From Britain, the steam hammer, hydraulic press, locomotive and mechanical loom. Back home, in those early decades Victorians built Australia's first telegraph line and first steam railway, and installed night lighting at the MCG before Thomas Edison produced his lightbulb. Victorians were also social pioneers, and now Melbourne is Australia's capital of biomedicine. This speech is an ode to my home state and an expression of optimism about its potential in the world of science.

How much do I love Victoria? Well, put it this way, I've got a son named Victor. And it might have turned out very badly for him if we lived in Tasmania and applied the same rule. But luckily for all of us, Victoria is home.

There are about six million people who choose to live in our state, six million people with the good luck and good taste to be Victorian. And so many of them are exceptional people that I refuse to accept they could all be wrong. I'm a scientist and this is my evidence-based conclusion. A toast to six million Victorians!

Now there's a downside to being one of six million right-thinking people. It means the pressure of being the official Victorian of the Year is enormous. Look at it from my perspective. I inherit a title from Judith Durham, and then I bequeath it to Mike Brady. That makes me just the nerd from Central Casting in between.

I can't sing. I've never appeared on a postage stamp. No-one has ever made a musical about my life. At best, in a certain crowd, I can occasionally pass for Doctor Who. I can write. I've published a lot. And funnily enough, I've been waiting all my life for the right occasion to read out some selections from my PhD thesis, titled "Chloride-selective cholinergic receptor-channels in snail neurones", which I happen to have with me tonight.

"I can't sing, I've never appeared on a postage stamp, no-one has ever made a musical about my life; at best, in a certain crowd, I can occasionally pass for Doctor Who"

But I sense that this is not the right occasion. What I'd like to offer you instead is a journey through time, and a vision of the future through the prism of the past. It won't be a snapshot of the future, because the future is too hard to pin down. No, it's more like a screensaver, all blurring colours and dancing lines. Focus on the lines, and the image dissolves. Look for the patterns, and then you'll find the line you want. But to think in patterns you have to think backwards as well as forwards, and sideways as well as straight ahead. So that's how we're getting to the future tonight, backwards and sideways.

We're starting in 1851 and we're going to the opposite side of the world. 1851. A year of three momentous events. The year the colony of Victoria was born. The year the gold rush was proclaimed. And also the year of the Great Exhibition, at the Crystal Palace, in London. Our prism to the past. The Crystal Palace.

Now there was a time when every boy and girl in Australia knew the story of the Crystal Palace. These days, you say Crystal Palace and people assume you're talking about the British football team. If they're slightly older, they think of Superman and the Fortress of Solitude, which was also a crystal palace, but one in a frozen wasteland only accessible to Kryptonians and Lois Lane, and not relevant here. I'm speaking of the original Crystal Palace, a spectacular confection of iron and glass that sprang up like a fairy castle in London's Hyde Park in 1851.

This Crystal Palace was more than 500 metres long and 40 metres high, with close to one million square feet of glass. It was a display case like no other. And the jewel it was built to house was the Great Exhibition. Inside were more than 100,000 displays from more than 15,000 contributors, gathered from all across the globe. The richest porcelain and tapestries from France. An ivory throne from India. Watches from Switzerland and furs from Russia. And from Germany, a family of taxidermied cats, arranged as a tea party.

But it wasn't all cultural artefacts in dubious taste. There was the best from the British, the mighty iron gods of industry. The steam hammer. The hydraulic press. The locomotive, and the mechanical loom. And alongside these incredible machines were the curious models of things to come – submarines and bicycles and hot-air balloons.

The variety was staggering, but the overall impression was clear. Here, in the heart of London, in a chrysalis of glass, was the power of human potential. It sprang from the vision of Queen Victoria's husband Prince Albert, a globalist and techno-optimist ahead of his time. He didn't just come up with the idea; he personally chaired the Royal Commission that brought it to life. The plans for the building were signed off just days before the Queen signed the documents that would establish Victoria as a separate colony.

It is curious to think that Queen Victoria might well have had the plans for the Crystal Palace and the paperwork for the colony of Victoria on her desk at precisely the same time. And when our Separation Day arrived, in the following year, the Great Exhibition was at its height. Victoria was on its way to becoming a state of six million people and the Great Exhibition was on its way to welcoming a total of six million visitors.

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Now, if you were looking for Victoria's contribution at the Crystal Palace, you would have come home disappointed. The Great Exhibition opened too early for the colony to have its own presence. And the contribution of the other Australian colonies was fairly dismal. There was a good showing for our Merino wool, some samples of wood and at least two barrels of beef fat. As they say, all very interesting, but nothing to compare to taxidermied cats.

But I suspect we caught the sparkle from London, the spirit of science, of learning, of industry and invention. Because in that year, 1851, the settler population of Victoria doubled, and doubled, and doubled again. There were 10 times more settlers in the colony at the end of 1851 than at the start.

They founded the University of Melbourne, the Athenaeum, the Royal Botanic Gardens, the State Library. They built Australia's first telegraph line, from Melbourne to Williamstown, in 1853. Then they built Australia's first steam railway, from Flinders Street to Port Melbourne, in 1854. They lit up the MCG with electric arc lights as early as 1879, so football could be played at night. That means that we had night lighting at the MCG before Thomas Edison produced his revolutionary lightbulb.

And we weren't just early adopters in technology – we were social pioneers as well. The eight-hour day. Votes for women. Workers' rights. Victoria was known as the "working man's paradise", because the wages here were the highest in the world.

And so it was that in 1880, barely a generation on from the Crystal Palace, the Great Exhibition came to Melbourne. We built our own display case – the Royal Exhibition Building in Carlton. But everyone knew that it was really Victoria itself that was on show. Victoria, the tiny colony at the bottom of the world, that didn't make the catalogue in 1851, was now the global host. And our greatest days were still to come.

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You can put it down to gold. But other nations had natural resources, and commodity booms, without anything like Victoria's success. Argentina is a case in point. In the early 1900s, Argentina was one of the 10 richest nations in the world, with one of the fastest rates of annual growth. Prior to the First World War, its income per capita actually surpassed the levels in Germany, the Netherlands and France. But Argentina declined while Victoria, and Australia, continued to prosper.

We built strengths not just in mining, but in agriculture, manufacturing, healthcare, education, transport, banking and engineering. And we grew rich not just in material terms, but in the things that make life worthwhile. A baby born in the state of Victoria today can expect to live longer than Queen Victoria, ruler of the British Empire. Think about it. The average person in our state today lives longer, in better health, and greater comfort – with more opportunities to travel, more things to eat, and more cultures to experience – than one of history's most privileged women.

Every year, *The Economist* magazine, which I love almost as much as *Cosmos* magazine, puts out a ranking of the world's most liveable cities. Melbourne has topped it for six years and counting. So you could say that Victoria was not just born in the year of the Crystal Palace, it breathed in the same spirit and it bore out the same promise.

Last month Elizabeth and I went to Italy for a family wedding. We had the opportunity to travel around. What we saw in so many places was a sense of pride. People took pride in their history, pride in their community, pride in their shared potential. They felt honoured to be part of something bigger and more enduring than themselves. That's the real gold. And Victorians have it in spades.

That is not to suggest that those Victorian Victorians were perfect. Like the builders of the Crystal Palace, they could be arrogant, prejudiced and stubborn. They also had some appallingly bad ideas, like introducing carp to the Royal Botanic Gardens in 1859. In the same year, they introduced rabbits, so that they could shoot them for fun.

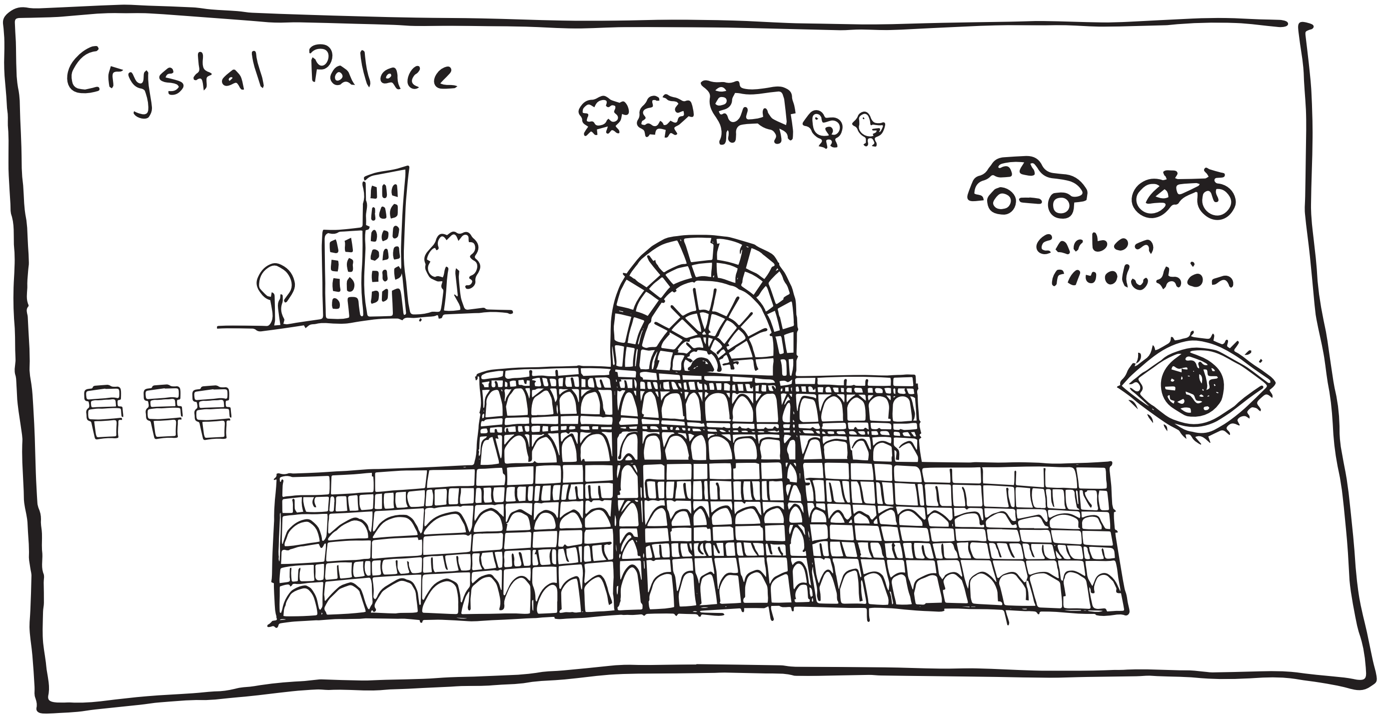
> ***"Doing nothing doesn't mean we're playing it safe"***

It is a reminder that we never touch the web of fate with perfect knowledge of the consequences, either the benefits or the risks. Some people would say that's a reason not to change things ever. But doing nothing doesn't mean we're playing it safe. It means we're doing nothing. Instead we must act, while keeping in mind the web of fate, and do our level best to read the patterns. Then we have to work out how to shift them, the smart way.

* * *

So let's go about it tonight like true Victorians. Let's imagine that we had our chance again to host the Great Exhibition in our own Crystal Palace 2.0. Imagine that the world came together once more, here in Melbourne, to showcase everything that human beings make and do and dream. What would we put on display? One rule only: no cats allowed, dead or alive. Let me offer a few suggestions.

First, the display stand I will volunteer to stand by. It's devoted to the Bionic Eye. In itself, it's amazing technology. A small digital camera in a pair of glasses transmits high-frequency radio signals to an implant in the back of the eye. The implant converts the signals to electrical impulses that are passed to the processing centres of the brain through the optic nerve. But it's not just the raw genius embodied in that device. It stands for all the expertise we have clustered here in Melbourne, the undisputed capital of Australian medical research. It's not just biomedicine. It's coding and chemistry, and optics and genetics, and electrical engineering and clinical experience, and more. You need all of them to deliver a miracle the science way. So tick to the Bionic Eye.



Second, the display we'll use to draw in the crowds – the best of Victorian farming. We'll have lambs and chickens for the children and wine for the parents. But we could take our pick. From apples to zucchinis, you name it, we grow it. And we won't just showcase the quality of our produce. We'll demonstrate the incredible pace of innovation on farms.

How about the E-Shepherd? It's a GPS collar for sheep and cows, invented in Victoria. The farmer determines the coordinates of their virtual fence. And when the animal wanders outside the boundary, the collar sends an audio signal that irritates it until it goes back the other way. So the farmer can move the fence and the herd by tapping their phone. Brilliant.

Third, to Victorian manufacturing. I'm thinking of a Victorian company named Carbon Revolution, the maker of the world's only one-piece carbon-fibre wheel. It's twice as light and 13 times as strong as the standard aluminium equivalent. We make them in Geelong, and you'll find them on Audis, BMWs and Porsches. They're that good.

Fourth, our nine universities and a vital export, education. If I had a favourite, it would be Monash, where I was Chancellor for eight years. But of course I would never have a favourite.

Fifth, something to capture the warmth and charm of Victorians. Let's make it the KeepCup. Takeaway coffee usually comes with a side order of guilt – the disposable cup. The KeepCup lets us have our great coffee in a barista-approved reusable cup. I bought mine in Queenstown, New Zealand. But it was designed and manufactured right here in Melbourne. As all of you who travel will know, you have to be in Victoria to have a great Victorian coffee. But you can have an inferior, non-Victorian coffee, in a great Victorian KeepCup, anywhere in the world.

Five suggestions. There's a start. There could easily be many hundreds more. And we could throw in two barrels of beef fat, for old times' sake. Folks, it's a beautiful thing, we've made the Great Exhibition Great Again.

Now here's something else that was remarkable about the Great Exhibition of 1851: it actually turned a profit. The proceeds were used to establish some of London's finest institutions: Imperial College, the Museum of Natural History and Science, the Victoria and Albert, and of course, the Royal Albert Hall. They also paid for science scholarships, which are still offered today. Those scholarships have supported 13 Nobel Laureates, including New Zealand's most famous physicist, Ernest Rutherford. We could call that an excellent return on investment. Naturally, we would aspire to do the same.

So what will we do with the stupendous profits from Crystal Palace 2.0? Here's a thought. We could invest in science education. There's a misconception that science is useful for scientists, and optional for everyone else. Every time a child leaves school with that belief, we have failed. We have failed to give that child the full set of tools to navigate his or her world. And we have failed to best prepare that child for a better future. And so we have failed ourselves. But just imagine what we could achieve, if we inspired every child with the joy of science, and gave our science teachers our every support. Imagine what our legacy could be. Just a thought.

But even if I can't send you away with pots of money, I hope we can leave our Crystal Palace tonight with something more important. It's just this: an unshakeable conviction that the future will be great. Let's get on with it.

44. Lessons from my Father

November 27 2018 | Acceptance Speech for a Doctor of Letters honoris causa *from Macquarie University*

It was no accident that I became an entrepreneur, combining a PhD in neuroscience with a love of invention. I inherited this from my father, who survived the war working in a textile factory in Siberia before he emigrated as a young man to Australia, where he built a large and successful business as a clothing manufacturer. What I learned from him was not only inherited, it was taught: hard work, the value of creativity and a strong moral compass. This speech was delivered as I accepted an honorary doctorate from Macquarie University 72 years after my father, David Finkel, arrived in Australia. This speech could have been titled "Nature versus Nurture".

A few weeks ago I went bicycle riding along the banks of the Yarra River in Melbourne. It was a sunny Sunday morning and I was joined by my wife Elizabeth, my son Alex and my daughter-in-law Brinley. After the four of us had been riding for some time, we passed by coincidence near to the factory that my late father David Finkel had owned in the suburb of Abbotsford. At this point, I suggested we hop off our bikes and take a break.

I assure you this wasn't because I was out of breath. Rather, I proposed stopping because I wanted to reminisce about my father. I'm not usually a sentimental person. I try to live in the present with one eye on the future. But as my mind turned to the business which Dad had worked so hard to establish, I realised that I had never conveyed much to my son Alex about his grandfather. Alex was born many years after Dad died so never had the benefit of his presence. I felt that I wanted to share my memories.

Today, as I reflect on what I have done in my life to merit the distinction of an honorary doctorate, I am similarly drawn to speak about a person who influenced me greatly. For as I get older, I see more and more how my achievements are shaped by the values and attitudes of those who have influenced me. With that in mind, I would like to share with you, too, what I learnt from my father.

But first, I feel it is my duty to tell you that, just 14 years after Barack Obama published a memoir entitled *Dreams from My Father*, he was elected President of the United States of America. Yes, you heard me correctly. When Barack Obama shared his father's story, it began his journey to the Oval Office. To Commander in Chief. To Leader of the Free World. You will be pleased to know, however, that I hold no such lofty ambitions. Nor do I intend for my recollections to fill an entire book. I merely wish to convey a little about my father in the hope that it is of value to you.

In what is an uncanny coincidence, Dad arrived in Australia 72 years ago to this day. He and his brother were on the first ship to bring out Jewish Holocaust survivors. The *Ville d'Amiens*, a French steamer, docked at Circular Quay, Sydney, on 26 November 1946.

Dad was 32 years old. He was born in Bialystok in northeastern Poland and as a young man had been sent by his father to the southern part of the country to establish a rug-making business. But the Second World War interrupted this venture.

> ***"In those early years he could only afford one suit, but that he handstitched it so that he could wear it inside out – that way everyone would think he was a wealthy man with two suits"***

Being Jewish, Dad's family suffered Nazi persecution. Many of his relatives were murdered. Others managed to survive. Dad spent most of the war in Siberia, and for a while he was lucky enough to find a job working in a textile factory.

Yet when he arrived in Australia, he had nothing except the desire to start a new life. He soon met his future bride, my mother Vera, whose family had migrated before the war. Mum tells me that the first time she met dad she knew she would marry him, not just for his good looks but for his charm and initiative. She tells me that in those early years he could only afford one suit, but that he handstitched it so that he could wear it inside out. That way everyone would think he was a wealthy man with two suits.

Yet by the time he died some 30 years later, Dad had become a leading businessman. He had worked hard to build a large clothing business that employed over 400 staff. He had given his children the life he himself missed out on. And, most important, he had bought a second suit.

Dad passed away in 1974, when I was just 21. It was a young age to lose my father and I would have liked to spend more time with him. But I am grateful for the time we had together and for the lessons I learnt in those years.

One of them was the value of hard work. I remember Dad explaining the credit squeeze to me in the 1960s. It was a time when the banks tightened their lending policies, meaning that businesses lost their overdraft facilities and thus their ability to expand and employ more workers. The financial pressure on the average person and small businesses was excruciating. Dad's approach was pragmatic and long term. He told me that you had to work hard to survive the tough times so you could thrive in the good ones that followed. He also advised me to only ever borrow from a bank because banks always take care of you and never lend you more than your ability to repay. Though I doubt he would give that particular advice today.

From Dad, I also picked up my lifelong commitment to creative design. As his business grew he built the factories into which the business expanded. I mean that literally. He spent many long nights sitting at his desk with a large sheet of Mylar, a clutch pencil and a Staedtler eraser, drawing the designs for the next factory or factory extension.

David Finkel, 1963
PHOTO: Alan Finkel provided

Years later, as a PhD student in electrical engineering, I too spent many long nights at my desk with pencil and paper, filling in the details of my electrical circuit designs. Two years of postdoctoral research in neuroscience were similarly punctuated by long nights at my desk with pencil and paper, and soldering iron and electrical components. When I left academia to start my own business in the United States, my efforts to manufacture scientific instruments were equally informed by my father's example.

It goes to show that there's no tension between working hard and being creative. On the contrary, it's those who work hardest who have the soundest basis for creativity.

Finally, though my father was proud of his success, I learnt from him that far more important than another factory, or another suit, are the principles that guide one's life. Dad was a generous philanthropist and I gained much of my moral fabric from him. Just one example that has stayed with me is my father opening the door to the rabbis from synagogues in Melbourne and from Jerusalem who sometimes called at our home. Though he was not a religious man, Dad always invited them in, spoke to them with warmth and respect, and gave them something to pass on to their communities. Even at a young age, it was an illustration to me of charity being the highest virtue.

Of course, I have come to learn a great deal from many people besides my father. Some people have helped me to develop a deep knowledge of particular fields. Others have nurtured my innate curiosity or provided advice at key moments. Yet more have been a source of support or comfort when I have needed it.

> ***"Though my father was proud of his success, I learnt from him that far more important than another factory, or another suit, are the principles that guide one's life"***

I was lucky to have as my PhD supervisor a great scientist in Steve Redman. He taught me the value of persistence and of committing to quality above quantity.

Then, when I was a postgraduate, a renowned neuroscientist named Paul Adams from New York visited my lab. After I explained to him one of the pieces of electronic equipment that I had personally designed and constructed, he asked me on the spot a question that transformed my life. He asked, "Wow, Alan, could I get one of those?" I was ready for a change from research, and I started my own business within a year. From this, I learned that luck owes a lot to the hard work and open communication that precedes the fortunate moment.

Later when I was at Monash University, the then Vice-Chancellor Ed Byrne taught me by example what qualities one needs to succeed in a large and complex organisation. An ability to manage in all directions. A capacity to address the concerns of all stakeholders. And a resolve to navigate towards a clear vision.

I'm sure that any University Council would agree that this is no mean feat. But I'm sure they would also agree that there is value in learning from others. And I mean this not just in the academic sense of mastering a subject, but also in the broader sense of being guided by people who have experienced something of life.

My father was one such person for me. As I stood with my son Alex on the banks of the Yarra a few weeks ago, I was thrilled to be able to share with him some of those lessons that I absorbed from my father and which I have articulated today. The importance of hard work. The value of creativity. The need for a strong moral compass.

Dr Finkel recieves his Doctor of Letters honoris causa from Macquarie University's Vice-Chancellor, Professor S Bruce Dowton, 2018
PHOTO: Lucy Mowat/Macquarie University

I would add to this a lesson that I learnt not from my own father but from the man who is regarded as the father of neuroscience, the discipline in which I have forged my career. And that is to retain a sense of wonder. Spanish neuroscientist Santiago Ramón y Cajal saw pattern and order and an intricate kind of beauty in the 100 billion cells that make up the brain of a human being. I hope you keep at the front of your minds that same sense of marvelling at the world.

When he disembarked at Circular Quay on 26 November 1946, David Finkel could not have imagined that 72 years later his son would be accepting an honorary doctorate just a kilometre away. It is a wonder, and I am deeply grateful to Macquarie University for this honour. I owe much of it to my late father and to the many other people who have, to paraphrase the University's motto, gladly taught me about life.

45. Australian Science Communicators

March 1 2016 | Keynote Address to the Australian Science Communicators National Conference

Of many things I love in life, two that feature in this speech are chocolate cake (especially the ones my mother used to make) and grammar (truly). What's not to like? The first is so important that many humans are reputed to have a second stomach, held in reserve for processing chocolate cake at the end of an otherwise too generous meal. The second is the syntax of language, which is itself "the freight-way of ideas". This speech to science communicators is about journalism and science writing, and where the excellence of human journalism will stand out from the analytics produced by the explosion of artificial intelligence powered algorithms. It is also about how science journalists have to join forces through services such as the Australian Science Media Centre to compensate for the diminishing investment by mainstream publishers and the lack of professionalism in social media publications. I argue that people will always be needed to tell human stories in ways that make us think. In science communication this is crucially important, not least for conveying incredibly complex ideas in ways that will help policymakers and investors understand and value them. There's also a voracious public appetite for science news – witness the way the discovery of gravitational waves made the front page of the New York Times – but it's an appetite built on much more than information; it's built on human wonder.

I'm a stickler for spelling and grammar. It irritates my wife, my children and my staff no end. "Alan, you're an engineer," they tell me. "You're supposed to spell like someone who's really good with numbers but communicates in grunts." I tell them they're wrong. I don't care about language in spite of the fact that I'm an engineer. I care about language because I'm an engineer.

After all, what do engineers and scientists love best? Systems. Structures. Algorithms. All frameworks that deliver reliable outcomes with minimum waste and maximum precision. And what is language but the delivery vehicle for the most important raw materials of all?

Language is the freight-way of ideas. It is the optical fibre our ancestors used to communicate to their descendants. Indeed, language is the greatest civil engineering project of all time. We needed language when we were making clothes out of bits of woolly mammoth. How much more do we need it when we are writing algorithms – the clearest of logical thinking that must follow explicit rules?

The grammar of algorithms is important because the hardworking computer operating systems on which they run are completely bamboozled by the simplest of spelling or grammatical mistakes. Engineers have no choice but to care about getting it right. We even care about split infinitives. My staff might urge me to boldly go, but on my watch, we'll be going boldly.

The principles of good writing

Just as there are principles and forms for words and sentences, there are principles and forms for writing. We know this because we can teach those things to robots – or, more accurately, we can program robots to learn them from us. I'm referring, of course, to artificial intelligence, or AI.

Consider the company Automated Insights, with its software programme Wordsmith. Wordsmith takes anything you can put on a spreadsheet and turns it into an article or report. Think stock market summaries, annual reports, football re-caps, real-estate reviews. Thus far Wordsmith has created more than a billion automated articles and reports, for clients including Associated Press and Yahoo. And it's not the outer limits of what AI can already do. Google, for example, is working on software that writes city guides based on the billions of images tourists upload to the web. Imagine what more we could do with image recognition in future. There are 1.8 billion images posted online every day that reporters never see. What stories could AI find that we've never told?

Or imagine what a robot could learn about speaking human by trawling every work in the literary canon, or every sentence ever tweeted, in every language we have ever recorded. Could that robot ever compose the line "I have a dream"?

> ***"Imagine what a robot could learn about speaking human by trawling every work in the literary canon, or every sentence ever tweeted, in every language we have ever recorded"***

They say that speechwriters to the US President are called the White House ghosts. Are we spooked by the coming army of robot ghosts? If you're feeling threatened, you're possibly in the wrong room. If you're already thinking through the consequences, then we need you.

Embracing the AI opportunity

The consequences of AI will be an opportunity for high-quality science communication if we human writers meet the revolution with the qualities we celebrate in our craft. Passion. Rigour. Flair. I've got three reasons why we should be optimistic.

First, AI is not an existential threat. In fact, it's probably the best argument I've ever seen for your continued existence. Bear with me here. Yes, AI can recognise and generate a gee-whiz, clickbait headline. And yes, it can churn out workmanlike text. If that's your sole definition of good writing, then you've just been displaced. But it's not my definition and I hope it's not yours. Good writing doesn't measure its success in eyeballs engaged but in minds inspired. It dares us to think, with the oldest human technique of all – the story. There's no AI on the market that can match it, and I don't expect to see it anytime soon.

> ***"I marvel at the progress we've made in AI, but I marvel just as much at the limits we're struggling to transcend"***

Of course I marvel at the progress we've made in AI. But I marvel just as much at the limits we're struggling to transcend. Both the achievement and the magnitude of the challenge tell you something about the awesome power of the human brain. We would be a very sad sort of society if we thought we could get by without great stories and the people who tell them. AI will do the mundane, the routine, leaving time for human journalists to create vivid word pictures and write the stories we want to read. In that sense, AI ought to bring out the best in the humans.

Second, we're sitting on a gold mine. A data gold mine. Scientists are making more of it every day. We've just got to get the gold to market.

To give you one example, a story that broke this week from the United States. Many cynics have suspected for a long time that there's a lot of recycling of cryptic crossword clues. But no-one has been able to gauge the scale of it, until now. It took an engineer and a journalist to do it. The engineer built a database of 52,000 crosswords, dating back to the 1940s. Then he wrote a program to cross-match every single crossword, against every other crossword.

The journalist found the story in the data. More than 1,500 puzzles from a major publisher were at least 75% similar to previously published work. So thinking outside the box revealed the dodgy practices inside the grids. Now, it's spelled out, in black and white. Further proof that scientists, engineers and journalists are the great defenders of civilisation.

Third, I believe we can adapt to the forces restructuring the mainstream media outlets. For a long time, the gold standard in journalism was the full-time science reporter, able to assemble the ingredients and produce a masterful cake. As we know, those positions are scarce today and those that do exist are often insecure.

The science community has responded with clever services like the Australian Science Media Centre, supplying the equivalent of cake mix to the major news desks. It helps harried journalists to deliver a substantiated product, of guaranteed relevance, to mainstream readers. Today, however, it seems many journalists haven't even got the time to make up a cake mix. But the hunger for good content remains.

So, there are three routes they could pursue:

- One, the status quo. Take any cake you can get, from anywhere it comes, cost-free. Often, it's a media release from an interested party, so you can't be certain of the nutritional quality or the salmonella risk. But we know that a lot of outlets will still swallow them up and pump them out, verbatim.
- Two, the factory model. Harness AI to make the mass-produced equivalent of the Sara Lee chocolate cake. Sure, it's a good cake. But it's the same good cake you ate last week, and the week before. If you ate nothing else, you'd never know how great a cake can really be.
- Three, the Vera Finkel model, named in honour of my mother. Connect journalists with expert writers who can supply the home-cooked, masterful, one-of-a-kind production. Content with credibility, with style, made available to the mainstream reader.

In future, I think we're likely to see a combination of all three. We can wait for the first and second to lower the bar for science communication, or we can take the initiative now to adopt the Vera Finkel model. Even though it is the hardest to resource and make available at scale. I know that this model, on their initiative not mine, is on the agenda for the board of the Australian Science Media Centre. I expect it will come up in the conversation today.

Let me just repeat my absolute confidence that there is a need and an opportunity for the high-quality work you want to produce. Get the business model right and the market will respond. Markets are made by customers, in this case our readers. It should never be forgotten that our readers are intelligent, eager to learn and responsive to good narratives.

People want to listen

I've been thinking about eager, intelligent readers a great deal lately, in the wake of the announcement of the observation of gravitational waves. If you work in science communication, you know this story. And you will know that it's the Bermuda Triangle of communication. Everything difficult in a science communicator's brief is there:

- Cosmically enormous and infinitesimally small numbers
- Astronomy, advanced physics and cosmology, combined
- Jargon as thick as a physicist's beard
- Acronyms like a toddler let loose on a plate of alphabet spaghetti

Then there's the small matter of the theory of general relativity and the distortion of the fabric of space time. With a little bit of quantum squeezing thrown in for good measure. And yet, there it is on the front page of *The New York Times*. Trending on Twitter. Blowing the cat videos out of the water. Making waves of its own. Making it easier for me to explain the business case for Big Science.

A professional skill and a critical role

Speaking of which, it's worth pausing to remember just how influential you really are. Governments can do many things, but they will never make us reach for things we cannot see. It wasn't governments that thought of the LIGO detector for gravitational waves. It was scientists. Just as it was journalists who explained the results, to inspire people all around the world to dream of the futures that might now unfold.

Of course you can’t do it alone, but you are the critical connecting link. So we need you today, more than ever. My challenge to you is simply this: help Australians to appreciate science deeply, not just to note it. The love of science means respect for intellect. The thirst for opportunity. And the determination to put in the effort. So continue to be determined to make chocolate cakes that will win the hearts and minds of Australians.

46. The Innovation Imperative

March 5 2019 | Keynote Address to the Australian Institute of Company Directors Governance Summit conference

Artificial intelligence is entering the world in ways we might not have anticipated – with bots doing the work of debaters, lawyers, stockbrokers, and now even company directors. But so far and for the coming decades at least, robots don't have artificial general intelligence; there are abilities and insights that humans do better. This is specially so when it comes to company directors. My personal insight – not researched but based on experience – is that directors who do exactly what directors are expected to do are the ones who preside over company death spirals. They meticulously read all the information given to them by management, but miss all the clues that an insightful director should sense. Good directors have antennae that can sense the cumulative meaning of missing information and cut through deliberate or well-intentioned efforts to swamp the directors with reports or in some cases misleading information. For an AI to do more than what is taught to directors it would need artificial general intelligence, a capability that is still well into the future. This speech to the Australian Institute of Company Directors sets out five ways to be a good human director: actively inculcate a culture of integrity; know that transparency and trust are critically important; get the right mix of skills among board members; ensure you can give the job the attention it needs by not stretching yourself across too many boards; and talk to the people in your organisation.

In 2014, a venture capital outfit in Hong Kong, called Deep Knowledge Ventures, appointed the first robot director to a corporate board. They didn't do it simply to be first, although to the best of my knowledge they were. They didn't do it simply to impress their stakeholders, although I have no doubt they were spellbound by this appointment. The company did it because they were sick of the high failure rate in biotech investment.

To improve their investment success rate, they built an artificial intelligence, a robot named Vital, short for Validating Investment Tool for Advancing Life Sciences. Vital's job was to map the predictors of risk. She could crunch millions of data points across 50 parameters describing a target company – stock prices, clinical trials, IP holdings, personnel records, research grants and more.

Then, at the board table, she would vote on whether or not to make the investment. Of great significance, the human directors agreed not to go ahead without Vital's approval. She wasn't legally allowed to be a director, but she was effectively something better – a super-director, holding veto power on investment decisions.

At the time, most of us probably dismissed Vital as a PR exercise. I admit, I used her story three years ago to get a laugh in one of my speeches. Given that it's five years since Vital first appeared, I thought I'd check to see what's happened.

For starters, the company is still in business. Vital is still on the board. And waiting in the wings is her successor, Vital 2.0. The experiment was so successful that the CEO predicts we'll see fully autonomous companies, able to operate without any human involvement, in the coming decade. Stop and think about it – fully autonomous companies able to operate without any human involvement. There'd be no-one to come along to AICD summits!

Now I'm not here to prophesy the extinction of the human director, but I do want you to take Vital and her progeny as a challenge. We know that our respect for human directors has taken a battering. We've seen examples of shocking misconduct in some of our biggest companies. The humans at the top, the CEOs and directors, are copping the blame, and often with good reason.

At the same time, our respect for the capacity of AI systems has been greatly enhanced. We've seen stunning demonstrations, such as AI debaters able to form and articulate a persuasive case based on their parsing of hundreds of thousands of articles. We've seen AI lawyers beating the humans at reviewing nondisclosure agreements and contracts for errors and vulnerabilities. And we've seen AI stockbrokers, now ubiquitous on Wall Street. They're good at your jobs, and they'll keep getting better.

And an army of AI director-bots with all those capabilities could be licensed to millions of companies, displacing several million directors, and be upgraded every night. But those director-bots would still lack something vital, something truly vital, and that's what we call artificial general intelligence – the digital equivalent of the package deal of human abilities, human insights and human experiences.

The experts tell us that the world of artificial general intelligence is unlikely to be with us until 2050, perhaps longer. Thus, shareholders, customers and governments who want that package deal will have to look to you for quite some time. They will rely on the value that you, and only you, can bring, as a highly capable human being, to your role.

And they will look for boards that are structured to draw that general intelligence into a high-performing unit. The challenge is to appoint highly capable people who think first like good humanists, and second like good engineers. And I'm just as invested in this challenge as you are.

I've been a board member on four public companies, one in the USA, all of them in biotech – yes, I know, playing in Vital's territory – and I have chaired a number of not-for profit organisations. I've been a successful engineer, scientist, business founder and investor, a philanthropist and a university chancellor. And now, I am an advisor to government. I am currently leading the National Hydrogen Strategy development, am the executive officer of the National Science and Technology Council, Deputy Chair of Innovation and Science Australia, am a member of the Climate Change Authority and several other committees, and have led numerous government reviews. So, drawing on that experience, let me begin with the aspiration, my definition of the good director.

It goes without saying that you want someone who's competent, intelligent and well-meaning. But there are lots of competent, intelligent and well-meaning people – they're just not all cut out to be directors. We choose directors, or we should choose directors, because they are special, not because they are ordinary.

Good directors are not just auditors. They are fired with a sense of the company's mission and trajectory. Good directors have their own life experience, relevant and abundant experience. Good directors are not just passive. They make it their mission to go beyond what they're told. Good directors know they have no excuse to be ignorant, and that competent directors only fail to see problems if they fail to look.

On a well-functioning board, about half of the directors have executive experience in the same or a related field as the company's operations. On a well-functioning board, a majority of the directors have heightened olfactory systems. That's the sense you need to smell a rat. The sense you need to smell the smoke.

"On a well-functioning board, a majority of the directors have heightened olfactory systems, the sense you need to smell a rat, the sense you need to smell the smoke"

Above all, collectively the directors have to be the custodians of the vision and the culture. In every decision, they are constantly tending to the investment in the future. That means they have to be capable of asking and answering the question that AI systems can't answer, the question so clearly articulated by Kenneth Hayne. The question to be asked is, should we do this? Not, could we do this?

How do you define the "should"? I have my own often-repeated mantra that gives me simple guidance, and that is, the two reasons to be in business are fun and profit. And it applies to all organisations, not only for-profit businesses. The word "fun" can stand in for collegiality, fame, excitement or fulfilling your duty. The word "profit" obviously stands for monetary returns, but it could also stand for societal and environmental impact. Very importantly, the "and" is non-negotiable – fun and profit, not fun or profit. Without fun, employees are not motivated to drive profit. Without profit, you really can't have fun.

In that context, there's a particularly important role for the chair. The chair should be a mentor, a sounding board, a guide for the CEO. The separation of roles is clear. Management runs the company. The CEO and senior management live and breathe strategy and budget. Thus, it's management's job to develop the draft strategy and the draft budget for consideration by the board. It's the board's job to constructively challenge management's assumptions and directions. It's the chair's job to respect the voice of every director and get to a decision without bulldozing through the debate.

Earlier on, I mentioned the importance of thinking like an engineer. If an engineer compromises in the design of a bridge, tragedy ensues. If an engineer seeks perfection in the design of a bridge, it will be too expensive to build. Instead, engineers know that their job is the art of optimisation. A good engineer optimises the design to satisfy multiple parameters.

A good chair should do the same. Optimisation is making the best or most effective use of a situation or resource. So much better than compromise, which is the settlement of differences by mutual concessions. So much better than the pursuit of perfection, which is arguably doing nothing, nobly, in pursuit of your ideals. At a higher level, in a nutshell, the role of directors is governance and guidance.

> ***"If you just focus on governance, you're an auditor; if you just focus on guidance, you're a life coach; If you achieve both, you're a futureproof director"***

There I've used another all-important "and". If you just focus on governance, you're an auditor. If you just focus on guidance, you're a life coach. If you achieve both, you're a futureproof director. AI, eat your heart out.

That sort of leadership can occasionally emerge by luck, but in the best organisations, it emerges by design. So, let's set out some of the design parameters I've learned from experience. At this point I note that my most salient experience comes from being Chancellor for eight years at Monash University, a well-managed and successful entity as large and complex as many of our major public companies.

First design parameter: culture cannot be a passive thing. You have to act it, you have to talk it, and you have to teach it. Safety is a good analogy. Consider Rio Tinto. Like other mining companies, Rio Tinto has been constantly improving its safety practices. The number of injuries of any type has been steadily falling for decades, and dropped again in the decade to 2017 by another two thirds. Mining companies didn't achieve exemplary safety records by luck or by resolving to have fewer accidents. They didn't get there simply by installing safer machinery. Their achievement was possible because they changed human behaviour to focus on safety all the time.

This goes beyond the workplace. Rio Tinto, along with other mining companies, asks employees to report accidents that happen at home as well as at work. Not to be included in the corporate KPIs, but to raise awareness of the importance of safety in all aspects of employees' lives. Here are four practices of organisations that make an active commitment to safety.

1. They teach safety procedures to new employees.
2. They reinforce safety practices to existing employees.
3. They make sure employees are not penalised, directly or indirectly, for following safety procedures as their priority.
4. They avoid any incentives that would inadvertently lead to risky behaviours.

To actively commit to integrity, just take those four practices and simply replace the word "safety" with the word "integrity". These, then, are the practices to which exemplary organisations constantly commit:

- They teach integrity procedures to new employees.
- They reinforce integrity practices to existing employees.
- They make sure employees are not penalised, directly or indirectly, for following integrity procedures as their priority.
- They avoid any incentives that would inadvertently lead to dishonest behaviours.

That is, it takes much more than an occasional declaration of good intentions to achieve an exemplary safety or integrity record. Good boards ensure that the commitment is disseminated by management throughout the organisation.

My second design parameter for effective boards is that transparency and trust are critically important. Board members have to be confident to put issues on the table. My one bruising experience was, many years ago, trying to help management implement a significant redundancy package.

I was Chancellor of the University Council, meaning that I was Chair of the Board. Unlike most companies, we had elected staff on the board. That is, we had some board members who were elected to represent particular constituencies, with potentially conflicted interests. The conflict arises because it is not humanly possible for a representative board member to leave their staff constituency behind at the boardroom door. As a result, we found it extremely difficult to discuss the redundancies at the regular board meeting. It was terribly awkward and not consistent with good governance.

In response to that difficult period and some other uncomfortable interactions on Council, I felt that we needed to anticipate these conflicts rather than react to them. After seeking advice, I learned that a powerful way to maximise trust and transparency is to capture the expectations for confidentiality, courtesy and other board behaviour in a written charter, adopted and owned by the board.

A charter is not a legal document. Instead, it is an informal, plain-English playbook. The charter captures the key board practices and expected behaviours without having to go back to layers and layers of company constitutions, corporate law, ASIC regulations and ASX requirements. Not only does the charter avoid cross references and footnotes, it's actually written by the chair and directors, without input from corporate lawyers. It's owned by the people who pledge to adhere to it.

And a suggestion recently put to me is that another good way to build consistency of purpose is to include the board's purpose and values statement at the start of every board pack.

Third design parameter for effective boards: pay attention to the skills matrix. Board positions should never be offered as a retirement option for friends, or a reward for loyalty. Instead, every new appointment should meet the skill needs of the board. These needs should be specified in a skills matrix incorporated into the terms of reference of the membership committee. The skills matrix itself should be reviewed as the organisation pivots or evolves.


PHOTO: Australian Institute of Company Directors

It sounds so obvious, but when I led the review of the National Electricity Market in 2017, I was shocked to find that the board of the Australian Energy Market Operator, the company that actually runs the physical electricity system, one of the biggest and most complex electrical machines in the world, included only one technically trained person. I had expected at least a third of the board members to have power systems expertise in a company with such a technology oriented and critically important role. Needless to say, in our formal review, one of our 50 recommendations was to remedy this problem. I am pleased that the electricity market operator today has a better board skills mix and is functioning much more effectively.

Fourth design parameter: work within the bandwidth of humans. Your bandwidth. Being a chair takes a lot of time. It would stretch human bandwidth to breaking point for a person to be chair of more than two public companies. Being a director takes a lot of time. It would stretch human bandwidth to breaking point for a person to be a director of more than three or four public companies. And all of that human bandwidth is precious. So, one of the roles of the chair is to ensure that the directors are not snowed with documents.

A good way to do that is to break the board papers into two packs – essential documents and background documents. Every director should read every word of the essential documents pack, but should only need to refer to the background documents if there is a specific question. A particular irritant for me is blow-by-blow committee minutes. They take too long to read and the key issues are buried in the details.

One of my Monash University Council Members recommended that instead of presenting detailed transactional minutes to the full Council, the Committee Chair should provide a narrative report, containing insights into what was discussed and advice to the Council. The details should be provided separately in the background papers. This worked a charm and I have required this ever since for all board committees.

There is a trend now towards digital distribution of board papers. Digitally distributed papers save trees but they do not reduce the demand on the precious human bandwidth of board members. Saving trees and reducing the physical weight in the briefcase are important, so going electronic is a good thing. Unless! Unless shifting to electronic papers is seen as making it easier to include hundreds of unnecessary pages. The chair must remain vigilant and avoid the temptation to provide more than is necessary, just because it is easy to do so.

There will be times when management will want to bring forward a special initiative, such as starting up a new product line or a major joint venture – a special initiative that's obviously going to eat up bandwidth. In my Monash University days, for example, one such project was building the case for starting a new overseas campus.

A special project you might face in your company today could be how to capture the transformative opportunities made possible by artificial intelligence and machine learning throughout your organisation, so that the next Vital 2.0 equivalent might be a tool that improves your organisation's agility and competitiveness.

When these major projects arise, it can be helpful to appoint a task-and-finish committee consisting of just two or three board members. This special committee can meet as often as necessary, so the planning can progress, the board remains informed and other business can proceed. When the project is completed, the special committee automatically terminates. If you get it right you'll shrink the meeting packs, heighten the focus and boost the attendance.

For example, when I started as Chancellor at Monash University, we had 21 Council members, hundreds of pages per meeting, six two-hour meetings per year, plus an annual two-day offsite strategic planning conference. But is it reasonable to only think strategically once per year? Eventually we decreased to 15 Council members, split the papers into two packs, increased the number of meetings to eight per year and increased their duration to three hours. All of a sudden there was sufficient time in every meeting to think strategically and we found that the two-day offsite strategic planning conference was no longer required.

My final design parameter: don't be afraid to actually talk to people. Board members should have access to senior executives, to occasionally hear straight from the horse's mouth. Of course, board members should never issue instructions to executives or even hint at doing so, but there is something powerful that is learned by speaking to the troops.

With the blessing of successive Vice-Chancellors – the CEOs – at Monash University, once a year as Chancellor I did a tour of all the faculties and had a fireside chat with each of the deans. It gave me an expanded perspective that I shared with the Vice-Chancellor and deepened my understanding of the challenges and opportunities for the University.

So where does this bring us? My conclusion is that the sort of director you want to be is not the sort of director Vital and her AI progeny are going to displace. Remember, robots don't have noses. Robots can't have fun or understand what motivates others. And above all, robots can't tell humans what they ought to do. That's on you, the human director. So go forth and be vital, truly vital, and the future is yours.

47. Andy Grove and Setting the Bar High

June 10 2016 | Speech at the June Limmud, National Jewish Memorial Centre, Canberra

For me as an electrical engineer, Intel and its co-founder Andy Grove were heroes. But until preparing for this speech I didn't know anything about Andy Grove's background. I discovered he was born a Hungarian Jew who survived the Holocaust to leave for America, where in 1968 he co-founded what quickly became, and still is, the world's largest integrated circuit manufacturer. He got there through uncompromising hard work, passion for knowledge, and setting the bar high for himself. My greatest wish for Australia, one of the most prosperous nations on earth, is to follow his personal example, embracing his passion for knowledge and the drive to be the best.

The Jewish triple threat

You may ask what a Chief Scientist is doing at a Jewish literary and cultural festival. I'd tell you that science-trained Jews who can think and write are surprisingly common.

Call it the triple threat: Jewish, science-trained, literate. There's Albert Einstein, physicist and poet. Primo Levi, chemist and chronicler. Isaac Asimov, biochemist and science-fiction author. Elizabeth Finkel, molecular biologist and master of metaphor. And a name you may not know, but which I'm adding to the pantheon today: Andrew Grove. Engineer, entrepreneur, and what the Walt Disney Company would call "imagineer".

Andrew – or Andy, as he was known to the world – died in March this year. And I want to use this speech to pay tribute to his life and legacy. He was the very model of the modern mind. I mean he literally wrote the textbook for Silicon Valley.

Many people have written books about succeeding in business. Donald Trump has written 18! Or should I say, Donald Trump has published 18 books with his name and picture on the front. But Andy Grove's book is the one that the founders of Facebook, Twitter and AirBnB call "the Bible". Its title? *Only The Paranoid Survive*. So in its way, it builds on a strong theme in the Jewish literary canon.

But I don't want to spruik his book. I want to tell his story. It's not just the story of a modern man, but the ancient story of a resilient people – dispossessed, desperate, and determined. How do they rise? Through education. How do they prosper? By ideas. That's a story that can never be told too often. So, to begin.

The story of Andy Grove

Our story starts in September 1936, in Budapest, Hungary, with the birth of a boy called Andreas Grof. His father was a wholesaler of milk and cheese. His mother was a classically trained musician. They lived a middle-class life, in a comfortable apartment. At the age of three, Andreas contracted scarlet fever, and woke up in hospital with partial hearing loss. He recovered, over nine agonising months. And life went on. But not as it had been before, because a shadow had fallen on Hungary. I don't need to tell you its name.

Andreas's father was sent to the Eastern front, as a conscript in a Jewish labour battalion. His mother sewed yellow stars on to their clothes. And then came a day when she unstitched the stars, and told Andreas to forget his name and his Jewish identity. So Andy he became. They fled the city for a life on the run. And they survived by good luck and tremendous courage and terrible compromises. More than half a million Hungarian Jews did not – among them, Andy's relatives and friends.

When the Russians came they were called the "liberators". In truth, they were tyrants with different branding. Andy's father returned a broken man. And Andy went to school in Hungary with everything against him. At the start of the war, he was a partially deaf, overweight and hyperactive Hungarian Jewish child. By the end of it, he was partially deaf, under-nourished, hyperactive and impoverished.

And he wasn't just poor. To the Communists he was now considered a member of the hated "class exploiter" community to boot. His father had committed the crime of running a business before the war. So his sons, and their sons, and their sons, unto the third and fourth generation, carried the taint and were barred from university degrees.

But Andy had three things in his favour. The love of his family. His joy in life. And his passion for knowledge. He was insatiable. Nothing was too difficult or too obscure. He wanted to swim, so he jumped into an irrigation ditch and thrashed about. He wanted to read, so he took stacks of books into the air-raid shelters to pass the time. He wanted to impress girls, so he worked out how to make nitro-glycerine, the active ingredient of dynamite, and demonstrated it to the girls' class at school. It worked. He won his first kiss that way.

Above all, he wanted to write, to be a journalist. But the papers were Communist rags. And Communist rags don't make space for partially deaf, hyperactive, class-exploiter Hungarian Jews. So he pursued instead his second great calling, in science. He excelled at his studies. And as soon as he saw his chance, he leapt on a ship at the age of 19, to make his way to the US of A.

There he got his degree in chemical engineering from the New York City College – it goes without saying, first in his class. He was quoted in *The New York Times* the following day: "Friends told me that all I needed was ability. Americans don't know how lucky they are." After he completed his PhD at the University of California, Berkeley, he got swept up in the boom time for the semi-conductor industry. So life was good.

Andy and two of his colleagues decided they'd set up for themselves making computer chips, in a startup outfit they called Intel. There was Bob Noyce, co-inventor of the integrated circuit. He was the big visionary. There was Gordon Moore – as in the man who came up with Moore's Law that computer processing power will double every two years. He was the tech guy.

"I still have flashbacks to the days in the first year of building my startup when I approached the ATM at the bank with great trepidation, not knowing whether it would continue to be generous"

And then there was Andy. He was the engineer who thought he was the tech guy, but got lumped with the job that Bob and Gordon refused to touch. Business manager. To elaborate, that would be business manager in a cash-strapped technology startup. As Andy described it in his biography, "My first assignment was to get a post office box so we could get literature describing the equipment we couldn't afford to buy."

I know something about that feeling myself. I still have flashbacks to the days in the first year of building my startup when I approached the ATM at the bank with great trepidation, not knowing whether it would continue to be generous.

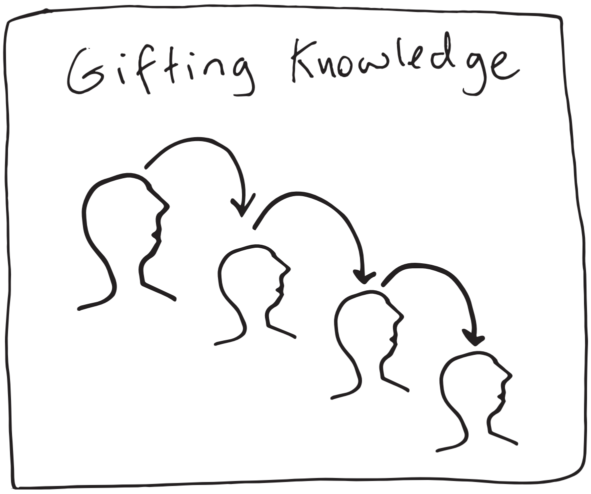
But of course Andy thrived. He threw himself into the role with a passion, as he always did. When the company fell into hard times, it was Andy who leapt into the CEO's chair. It was Andy who made the critical switch from memory chips to microprocessors. It was Andy who oversaw a 4,500% increase in Intel's market capitalisation from $US4 billion in 1979 to $US197 billion in 1998, making it the world's seventh largest company, with 64,000 employees.

And it was Andy who never stopped giving back to the country who had given him so much simply by giving him a chance. He was a mentor, a teacher, an advocate, a legend. Time's Man of the Year in 1997. Idolised by Steve Jobs. And right to the last, a proud, hyperactive, Hungarian-come-American Jew. So vale, Andy Grove, imagineer.

Setting the bar high

Now I've told you that story because I think you should know it. But I also want to reflect on what it might tell us about the secrets to success. There's no formula. There's only something that you understand when you come from a community so often left with nothing but the stuff in our brains.

I mean knowledge. I mean the passion for knowledge. I mean the obligation of a parent to give their utmost for the education of a child. I mean the obligation of a son or daughter to take that gift as their best inheritance and pass it on to the next generation in turn. You can read that lesson in the Proverbs: *Do not forsake wisdom, and she will protect you; love her and she will watch over you*.



You read it over and over again in Jewish history. You will see it in the stories of the people here today. Perhaps, like me, you've lived it yourself. But it's not just a Jewish story; it's a human story. And my greatest wish is that we embrace it today as the Australian story as well.

I worry when I see our schools sliding from a place firmly in the world's top 10 in science and mathematics to barely scraping into the world's top 20. I look around me and I see a nation which undoubtedly has its problems, but remains one of the most prosperous societies on the face of the Earth. So when did that lucky country accept that Top 20 might be sort-of good enough?

Call me paranoid. But take it from Andy Grove, only the paranoid survive. Let's all be paranoid and take the lesson from his extraordinary life. Educate our children. Embrace talent in all its forms. While we're at it, let's elect a few more scientists and engineers to Federal Parliament. But most of all, let's follow Andy Grove's maxim: take a little bit of the future, and make it your present.

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