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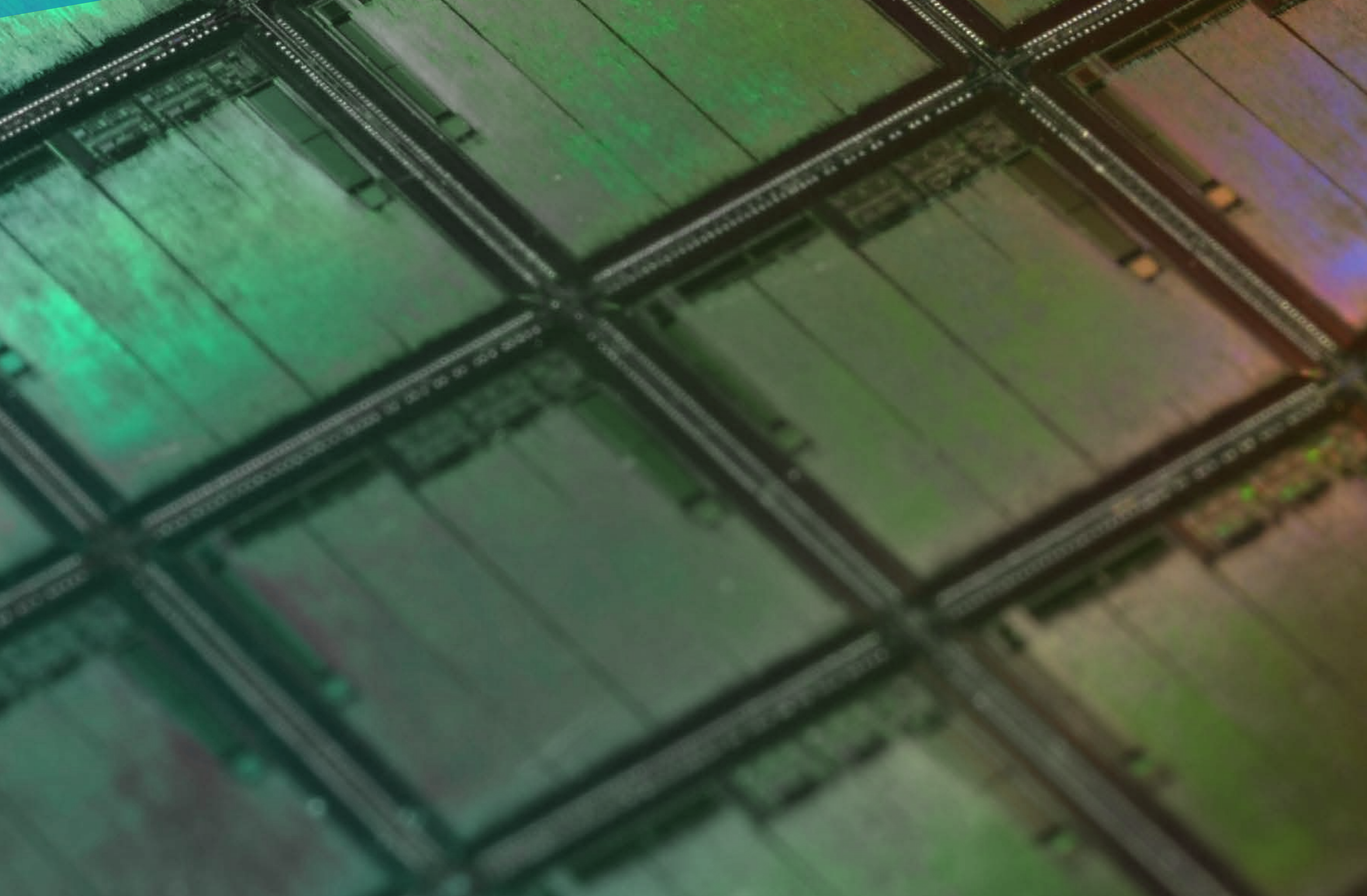
NATIONAL COMMITTEE FOR INFORMATION AND COMMUNICATION SCIENCES

SEPTEMBER 2019

Preparing for Australia's Digital Future

A strategic plan for information and communications science, engineering and technology



Preparing for Australia's Digital Future

A strategic plan for information and communications science, engineering and technology

NATIONAL COMMITTEE FOR INFORMATION AND COMMUNICATION SCIENCES | AUSTRALIAN ACADEMY OF SCIENCE | AUSTRALIAN ACADEMY OF TECHNOLOGY & ENGINEERING

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A correction was made to this publication in August 2019 after some copies were printed and distributed. The corrected text is on page 33 and is the second last paragraph, under the heading 'Department of Education'. If you have a printed copy you may like to check against this PDF that your version is the corrected one. If you have the original text, please note the change.

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ECF ELEMENTAL CHLORINE FREE
EMS ENVIRONMENTAL MANAGEMENT SYSTEMS
FOREST MANAGEMENT
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Contents

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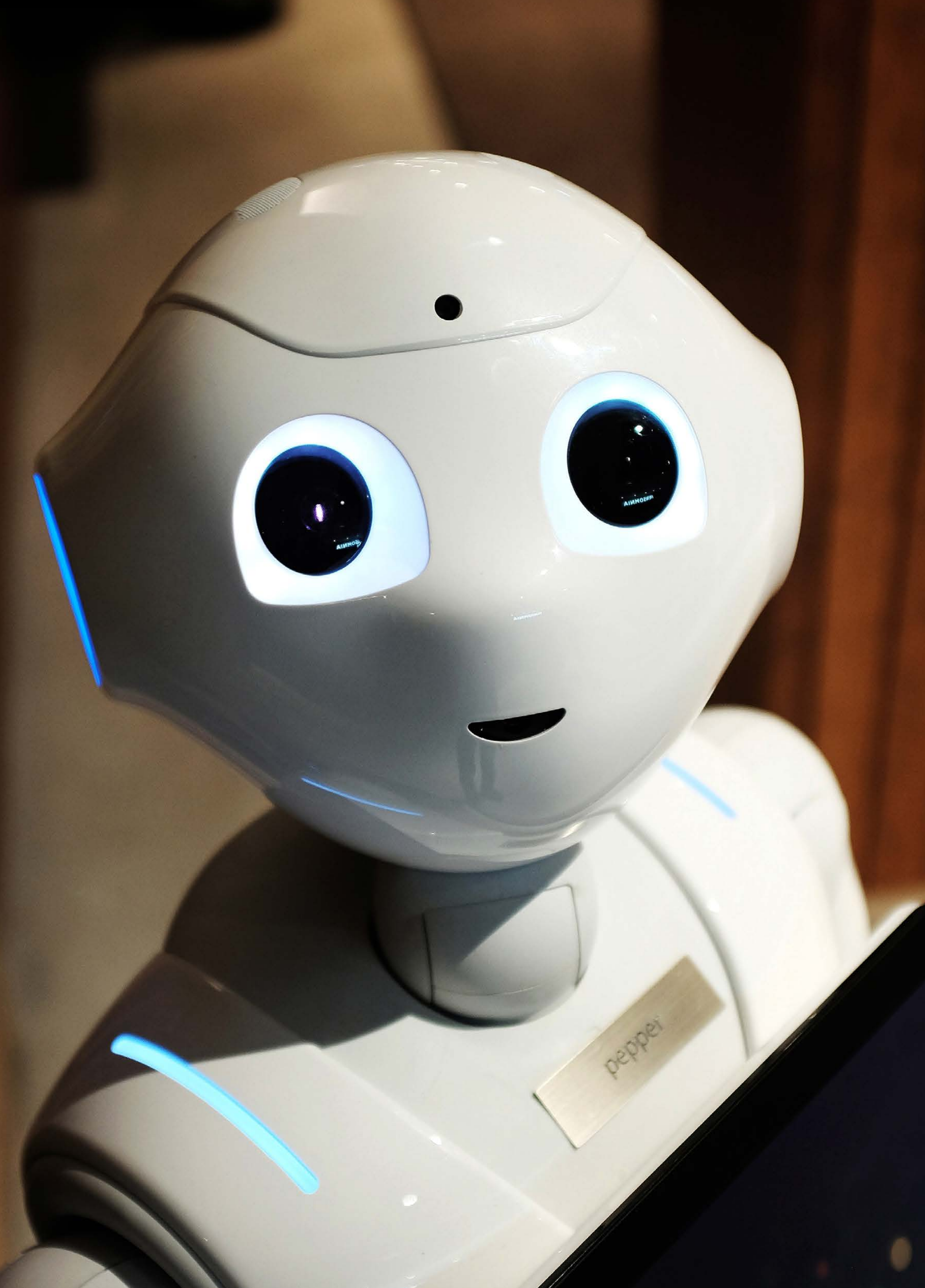

1 Foreword

Digital technologies permeate most aspects of Australian life and have transformed how we work and play. But the digital revolution has only just begun.

The pace of change is increasing and there are boundless opportunities for future digital technologies, applications and business models to further transform our society. The changes we have seen in the first nineteen years of the twenty-first century will only be magnified in the next nineteen years.

The Australian Academy of Science and the Australian Academy of Technology and Engineering strongly assert that to enhance our participation in the digital economy, Australia needs to plan strategically for what we call our digital future. This strategic plan is the result of a collaboration between the two academies. It is complemented by a series of digital readiness studies being undertaken by the Australian Academy of Technology and Engineering.

We need to strengthen the interaction between industry and the research sector to ensure Australia is well placed to capitalise on new technologies and be an early adopter, as well as play a role in inventing and bringing new technologies to market.

As Presidents of the two academies, we are delighted to present this strategic plan, 'Preparing for Australia's Digital Future'.

The plan is divided into several priority areas, and the recommendations point to new actions for industry, government and the research and education sectors.

The challenge now for these sectors is to work together to deliver on the recommendations contained here. We believe that there are synergies between the priority areas, and the greatest dividends will come from substantial action on all of them.

Professor John Shine AC PresAA
President, Australian Academy of Science

Professor Hugh Bradlow FTSE
President, Australian Academy of Technology and Engineering

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2 Preface

The Australian Academy of Science and the Australian Academy of Technology and Engineering have come together to develop this strategic plan to cement Australia's position as a digital nation.

The core focus of the plan is the need to strengthen the interaction between industry and the research sector to ensure Australia is best placed to realise and capitalise on opportunities in digital technology over the coming decade and beyond.

Without a clearly defined and outcome-oriented approach, as outlined this report, Australia risks falling behind as a digital nation.

The plan highlights five key priority areas for action. These are:

- promoting closer partnerships between industry and the research community
- strengthening our digital workforce and skills pipeline
- delivering whole-of-government action
- achieving reforms of the research sector
- promoting digital leadership in industry.

While progress on any one of these priority areas will be worthwhile, the greatest dividends will come from substantial delivery on all of them, recognising the synergies that flow between them.

Australia has a good story to tell on being a digital nation: this plan highlights just a few of the many examples of Australians converting great science and research into commercial products and services that improve our standard of living. But we need to do more.

The Australian Academy of Technology and Engineering is publishing a series of digital readiness studies that complement this strategic plan. The studies identify actions needed to respond to new digital technologies and their impacts on our society.

Economic studies show potentially substantial dividends from embracing digital technologies, adding as much as A$66 billion to the Australian economy by 2020. There will also be significant social benefits from accelerating and broadening our transition to a digital economy.

The challenge now for government, industry and the research and education sectors is to work together to deliver on the key priority areas and the recommendations contained in this strategic plan.

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3 Executive summary

This strategic plan is a collaboration between the Australian Academy of Science and the Australian Academy of Technology and Engineering. The objective of this plan is to help position Australia as a successful, forward-thinking digital nation.

The term *digital* is used here to describe information and communications science, engineering and technologies, including their implications for education and training, business, public policy and the innovation system. The plan focuses on improving the linkage between Australia's industry, innovation and research sectors to capture the opportunities that digital technologies present for Australia. It provides actions that will help research and industry stakeholders, and those who influence or set public policy, to identify, create and access these opportunities.

The plan presents 32 recommendations grouped under five priority areas:

- encouraging digital leadership in industry
- fostering research and industry partnerships for our digital future
- safeguarding and strengthening our digital workforce and capability pipeline
- ensuring whole-of-government action for our digital future
- delivering research sector reforms.

The plan also identifies five headline recommendations.

A taskforce will pursue implementation of the recommendations in this plan and monitor future progress.

Headline recommendations

Encouraging digital leadership in industry

Industries identify key opportunities for digital transformation and provide leadership in digital transformation by initiating strategies for collaboration with appropriate research agencies.

Fostering research and industry partnerships for our digital future

The visibility of publicly funded research be increased by developing and maintaining a readily accessible, up-to-date directory of Australian ICT research strengths and capabilities relevant to the digital economy, including international benchmarking.

Safeguarding and strengthening our digital workforce and capability pipeline

Universities and publicly funded research agencies reshape their research culture by placing substantially higher emphasis on industry experience, placements and collaborations in hiring, promotion and research funding.

Ensuring whole-of-government action for our digital future

Undertake a comprehensive national future-readiness review for the Australian digital research sectors, including their links with industry and opportunities to harmonise state, territory and federal initiatives.

Delivering research sector reforms

Develop a position statement on intellectual property across all Australian universities and publicly funded research agencies to remove intellectual property issues as a barrier to research update by industry. The position statement must emphasise the importance of partnerships with industry and recognise the value of intellectual property and cost of research. The position statement should be a first step towards a more comprehensive framework on intellectual property. Where appropriate, universities should be encouraged to promote open IP policies.

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4 Introduction

This strategic plan fills a critical gap in Australia's innovation system: despite broad and longstanding acceptance of the importance to Australia of information and communications technologies (ICT) and related scientific and engineering disciplines—grouped in this report under the broad descriptor of 'digital'—until now we have lacked an overarching strategic plan for a prosperous digital future.

This strategic plan is designed to help Australia do better. Numerous success stories demonstrate our ability to turn excellent science and research into commercial technologies and services that benefit Australia, yet our achievements are still significantly short of our great potential. As the changing global economy transforms the comparative opportunities available to us, we need a plan to help Australians recognise, act on and derive as much benefit as possible from opportunities in our digital research and innovation sectors. Similarly, meeting our changing capability requirements into the future will need astute and perhaps courageous planning.

It is tempting to describe a single digital transformation or to talk of a post-transformation world, yet digital transformations are not likely to end. They are continuously and rapidly evolving, driven by aggressive technology progress and accelerating uptake—and Australia is not driving. It is not realistic to expect Australia to lead in all aspects, but it is essential that, through strategic actions outlined in this plan, we are able to chart our own course.

The economic and social impacts of digital technologies are already pervasive and are only set to grow. For example, PwC, a consultancy, recently valued the global economic contribution of artificial intelligence (just a subset of the many technologies considered here) at US$15.7 trillion by 2030, more than the current total output of China and India combined[1].

Closer to home, digital technology is expected to add A$66 billion to the Australian economy by 2020[2]. Despite the impressive numbers, the imperative to proactively manage the ongoing digital transformation is not purely economic: societal well-being; cultural growth; accessing, using and creating knowledge; and many other parts of our complex lives are equally prone to transformation in a way that will leave no Australian unaffected.

The digital economy in Australia has been growing steadily as a proportion of our economy and is increasingly important to enable both domestic commerce and international trade. It is clear research investment in digital technology is only a tiny fraction of its potential contribution to Australia's future prosperity.

Although we're aware of the importance of digital technology to Australia, we lag most developed—and developing—countries in both business awareness and plans for the future[3]. Our international standing as a forward-looking digital nation is not only at risk, it is in active decline. Notable exceptions to this picture include headline successes such as Technology One[4] and Atlassian[5], and countless others such as Vitalcare[6] and VPI Photonics[7] that also demonstrate Australian researchers and businesses do have what it takes to succeed. Recognising Australian success is an important step towards normalising it[8].

1 PwC 2017, Sizing the prize: PwC's Global Artificial Intelligence Study: Exploiting the AI Revolution: https://www.pwc.com/gx/en/issues/data-and-analytics/publications/artificial-intelligence-study.html

2 ACS Australia's Digital Pulse:Driving Australia's international ICT competitiveness and digital growth 2018: https://www.acs.org.au/content/dam/acs/acs-publications/aadp2018.pdf

3 For example: InfoSys 2017: Amplifying Human Potential: https://www.infosys.com/aimaturity/pages/index.aspx

4 Technology One: https://www.technologyonecorp.com See also https://pearcey.org.au/2015-hall-of-fame

5 Atlassian: https://www.atlassian.com

6 Vitalcare: http://vitalcare.com.au

7 VPI Photonics: http://www.vpiphotonics.com

8 Organisations such as the Pearcey Foundation play an important role in celebrating the success of Australian ICT leaders across industry, research and government. See: https://pearcey.org.au

Three examples of Australian success

Technology One

Technology One was founded by Adrian Di Marco in 1987 and has grown into one of Australia's largest enterprise software companies. It has 14 international offices and has achieved steady domestic and international growth: roughly doubling in size each four to five years. It listed on the ASX in late 1999. Technology One has continued to reinvest 20 per cent of its annual revenue in R&D and recently committed to the Pledge 1% movement[9].

Vitalcare

Self-declared 'specialists in nana-technology[10]', Vitalcare develops and manufactures leading technology to make independent living safer and more enjoyable for the elderly. It has approximately 1000 installations nationally covering 50 000 hospital and aged-care beds in low- and high-care environments. It invests in Australian-based R&D with its own engineering workforce and collaborations with Australian universities and assembles its devices in Australia.

Aconex

Aconex offers collaboration solutions, digitally connecting teams across each of the stages of a construction life-cycle and has been used in more than $1 trillion worth of projects across 70 countries. It allows the numerous actors in construction projects—owners, contractors, construction and project managers, and other professionals—to collaborate easily and securely.

This document is the result of extensive consultation across industry, academia and government, and represents the synthesised views of over 200 professionals. It was guided by an expert steering committee convened by two independent learned academies. Steering committee members also conducted targeted interviews with senior industry leaders and researchers, developed an integrated framework to help consider the complexity of our digital future, and reviewed current research capability housed in Australian universities.

Through the consultation process the steering committee received a very clear message: Australian industry needs more from the research sector. This led the committee to look closely at ways that interactions and collaborations between industry and the research sector, particularly universities, can be enhanced. Several of the recommendations in this strategic plan focus on how the research sector can position itself to better work with industry and how the mobility of people between universities and industry can be improved.

Objective

The objective of this strategic plan is to position Australia as a successful, forward-thinking digital nation with an enhanced ability to translate our public and private sector ICT research into skills, innovation, public benefit and commercial success.

By implementing the recommendations of this plan, Australia will:

- **better align its research, industry and government sectors** to unlock the potential of the global digital transformation that is gathering pace
- **improve its track record of translating research into industry innovation** that enhances skills, commercial opportunities and public benefits
- **enhance collaboration, equity and diversity at all levels and across all sectors**, including practitioners and industries in fields that have not traditionally been active in the digital domain
- **improve its international positioning, visibility and impact** by promoting Australia's strengths across research and industry
- **strengthen the supporting environment that will shape our digital future**, including infrastructure, education and training, business, public policy and the innovation system.

This plan is intended for research and innovation planners and managers in industry, universities, publicly funded research organisations, and funding bodies such as the Australian Research Council (ARC) and the National Health and Medical Research Council (NHMRC). It is also aimed at strategists and planners in a variety of other organisations, including state departments of industry and innovation, state and federal education departments, university research policy managers, and industry bodies and associations.

Implementation of this plan will require action from individuals and organisations across all sectors. A key objective of the plan is to set out a mechanism for encouraging and facilitating implementation of the recommendations.

9 Pledge 1%: http://pledge1percent.org

10 A playful pun on the better-known, but unrelated in this case, field of nanotechnology.

Acknowledgements

The academies would like to acknowledge the contributions of many people from industry, government and the research sector who contributed to the development of this plan. Work on this plan began in the Australian Academy of Science's National Committee for Information and Communication Sciences and then became a joint project with the Australian Academy of Technology and Engineering's Digital Futures Working Group. Members of both of these bodies made important contributions to the plan. The following people were members of the steering committee for this project and oversaw the development of the plan.

Table 1. Steering Committee

Name	Position	Representing
Rod Tucker	Co-Chair	Australian Academy of Science
Glenn Wightwick	Co-Chair	Australian Academy of Technology and Engineering
Shazia Sadiq	Member	Australian Academy of Science
Svetha Venkatesh	Member	Australian Academy of Science
Mike Miller	Member	Australian Academy of Technology and Engineering
Jackie Craig	Member	Australian Academy of Technology and Engineering
Thas Nirmalathas	Member—Partner organisation	Melbourne Networked Society Institute
Iain Collings	Member—Partner organisation	Macquarie University
Jane Want	Member—Partner organisation	New South Wales Government
Julie Petering	Member—Partner organisation	Office of the Lead Scientist, Victorian Department of Jobs, Precincts and Regions

An integrated framework for our digital future

This plan recognises the massive volume of recent work by many organisations, each examining aspects of Australia's digital transformations and their impacts on our economy, our research and education system, or our culture. There is an increasing number and range of initiatives relevant to our digital future addressing a large and growing number of issues, led by many players across industry, governments, research and education.

However, while single issues or clusters of related issues can be addressed relatively comprehensively, there does not yet appear to be an agreed approach, method or framework that can help prioritise the many complex issues that have multiple drivers and many players.

It is those complex issues—often at the interfaces between science, society, government, industry and economics—that present persistent friction to progress and have limited our ability to, for example, translate basic research into commercial successes, or to bridge the science–policy interface at the rate and frequency that is often required. As a result, some of these shortcomings in our systems seem to persist and feature regularly in commentaries, reviews, and even public policy interventions.

Many of the metrics[11] used to establish the need for the various initiatives that are underway can effectively view one part of the system from one angle. It is however possible, as in other complex systems, that integrated approaches could more efficiently shape Australia's digital futures in ways that are less likely to encounter unexpected barriers.

In developing this plan, an integrated framework was developed to help identify linkages and guide thinking around the strategic actions we present as recommendations. It helps to address the limitations imposed by single viewpoints—or at least organises them for systematic consideration—and draw out the many connections between the **technologies** that underpin digital transformations, the **applications** of those technologies, and the various **issues**[12] that the technologies and their applications raise (or face). The resulting three-dimensional space (consisting of technologies, applications and issues) provides a useful visual model that reveals the breadth of digital influence in our world.

11 Metrics include, for example, student interest surveys, the proportion of women in senior management roles, innovation translation rates, numbers of patents, or the number and value of business–university partnerships.

12 The framework uses the word 'issues' in a neutral sense to describe a spectrum that ranges from 'enabling factors' through to 'barriers' which apply equally to technological as well as socio-economic issues. No firm distinction is drawn between enabling factors and barriers because of the interconnected nature of the framework—the same issue (for example, education) can be both an enabling factor and a barrier depending on the angle it is viewed from.

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5 Recommendations

Recognising the rapid pace of digital transformations, we have limited the planning timeframe to five years and directed recommendations towards implementable actions that support the goal of positioning Australia for a prosperous digital future.

There are 32 recommendations, grouped under five priority areas:

- encouraging digital leadership in industry
- fostering research and industry partnerships for our digital future
- safeguarding and strengthening our digital workforce and capability pipeline
- ensuring whole-of-government action for our digital future
- delivering research sector reforms.

Headline recommendations

The headline recommendations are drawn from the main body of the plan and are highlighted in purple.

Repeated recommendations

Some of the recommendations in this plan appear several times in a similar form. These recommendations were considered important enough to warrant repeating and are marked with this symbol: ⎘

Headline recommendations

Encouraging digital leadership in industry

Industries identify key opportunities for digital transformation and provide leadership in digital transformation by initiating strategies for collaboration with appropriate research agencies.

Fostering research and industry partnerships for our digital future

The visibility of publicly funded research be increased by developing and maintaining a readily accessible, up-to-date directory of Australian ICT research strengths and capabilities relevant to the digital economy, including international benchmarking.

Safeguarding and strengthening our digital workforce and capability pipeline

Universities and publicly funded research agencies reshape their research culture by placing substantially higher emphasis on industry experience, placements and collaborations in hiring, promotion and research funding. ⎘

Ensuring whole-of-government action for our digital future

Undertake a comprehensive national future-readiness review for the Australian digital research sectors, including their links with industry and opportunities to harmonise state, territory and federal initiatives.

Delivering research sector reforms

Develop a position statement on intellectual property across all Australian universities and publicly funded research agencies to remove intellectual property issues as a barrier to research update by industry. The position statement must emphasise the importance of partnerships with industry and recognise the value of intellectual property and cost of research. The position statement should be a first step towards a more comprehensive framework on intellectual property. Where appropriate, universities should be encouraged to promote open IP policies.

Encouraging digital leadership in industry

By their nature, small- to medium-sized enterprises (SMEs) are more likely to collaborate with SMEs than larger companies and can provide a unique and valuable type of industry leadership through collaboration. In a similar way, Australian SMEs may be more willing to respond to research collaboration opportunities as they arise than larger organisations that can afford to wait and interact with researchers on their own terms.

Despite the potential for Australian industries (which are often proportionally SME-heavy) to provide leadership in digital transformations, there remain for them real and perceived economic barriers that are beyond the scope of this plan. However, a greater understanding of the research capacity that is available and the type of transformations industry can lead is expected to deliver real dividends.

Headline recommendation:

1 Industries identify key opportunities for digital transformation and provide leadership in digital transformation by initiating strategies for collaboration with appropriate research agencies.

Recommendation:

2 Establish a mechanism for ongoing collaborative foresighting and agenda-setting between peak industry bodies and the research sector, assisted where appropriate by the learned academies.

Fostering research and industry partnerships for our digital future

Australia's research strengths are not necessarily aligned with our industry needs. Tellingly, *serendipity* is often a common explanation for the areas in which there is good alignment.

Visibility of Australia's digital strengths

Many industry leaders interviewed for this project found it very difficult to identify Australia's digital research strengths and to find researchers with expertise and skills in specific areas.

This lack of information about researchers and their strengths is a major challenge. Some areas of relative strength in Australia are quite small so personal networks can be effective, but our isolated pockets of strength are hard to identify and connect with from the outside. Breaking down the 'visibility barrier' would be a useful first step towards facilitating improved linkages between researchers and industry.

International visibility is important in attracting the best world-class researchers to come to or collaborate with Australia. However, relying on immigration of key, in-demand talent cannot be guaranteed, nor seen as an offset to other talent losses.

Headline recommendation:

3 The visibility of publicly funded research be increased by developing[1] and maintaining a readily accessible, up-to-date directory[2] of Australian ICT research strengths and capabilities relevant to the digital economy, including international benchmarking[3].

Recommendations:

4 Peak industry bodies in partnership with governments identify and promote Australia's digital strengths and foster global linkages that bring opportunities to Australia.

5 Universities and other publicly funded research agencies increase visibility to industries and government agencies by holding multi-organisation communication events that are relevant to specific capability areas.[4]

6 Conduct regular roundtables between technical leaders in industry and in academia to build a sense of shared understanding amongst Australia's technical leadership. Such roundtables could be facilitated by peak professional bodies.

7 Formalise research–industry brokerage activities in Australia to help match research capability with industry needs, and foster research–industry partnerships focused on developing future capabilities[5].

Using our comparative advantages

The major strength of Australian research is our research quality and reputation. As a nation, we have a collective mass of diverse talent in particular geographic and thematic areas. Our reputation also underpins our export income from international education. Separation of research from teaching risks diluting this reputation and weakening the export value.

1 An AI-based web and patent scraping service may be more technically tractable than a conventional directory.

2 The NSW Chief Scientist and Engineer provides an easily navigable example for NSW that could be extended to meet the specific needs of the digital sector: http://www.chiefscientist.nsw.gov.au/nsw-science-and-research-map

3 Such a project may be suitable for the academies to undertake jointly with state governments and the Australian Government.

4 This may include, among other options, extension of existing initiatives such as the Australia 3.0 roundtables (https://australia30.wordpress.com) or the DST Group's Partnership Week, or running more events with more specific scopes.

5 Recommendations 2 and 4 could both be achieved by a scheme similar to the former ARC Research Networks scheme (http://www.arc.gov.au/legacy-schemes), which among other successes seeded the Australian Nanotechnology Network.
It is noted that there are several excellent but isolated schemes already operating, such as the NSSN (NSW: http://www.nssn.org.au), the Defence Network (national: https://www.defenceconnect.com.au), the Cyber Security Network (NSW: http://sydney.edu.au/arts/research/cybersecurity) and the Defence Innovation Partnership (SA).

Australian universities and publicly funded research agencies need to recognise and maintain Australia's comparative advantages in the international landscape, to capitalise on the enduring value of our education system, our research sector and our small but potentially powerful industrial base.

Governments need to recognise the importance of a robust research infrastructure base. Such facilities are much easier to maintain than they are to rebuild should we lose them: allowing the necessary funding to lapse would be a false economy. Research infrastructure should be viewed widely, to include support and technical personnel.

Recommendation:

8 Universities[6] leverage the ARC's Engagement and Impact Assessment relevant to their research activities to serve as a mechanism for highlighting the value of the research to stakeholder groups.

Improving collaboration

Considering the dispersed and relatively isolated nature of the Australian digital sectors, we need to make the most of the industry and research capability that we have. Clusters of activity help maintain critical mass, and collaboration between industry and academia strengthens both.

Academic performance metrics, notably the 'publish or perish' imperative, can discourage academics from collaborating with industry and trying something entrepreneurial. At the same time, collaboration with SMEs and start-up businesses is particularly challenging, reflecting their limited financial capacities.

Collaboration also needs to be seen through a wider window—extending beyond the conduct and progress of research into the translation of research, which means encouraging, supporting and rewarding those who do the translation.

Recommendations:

9 Universities and publicly funded research agencies actively pursue opportunities to become focal points for businesses involved in developing and commercialising digital technology to cluster around capabilities. This may include, but not be limited to, co-location.

10 University researchers use sabbaticals in industry to gain industry experience[7] and create personal links between industry and research. One in two sabbaticals placed in industry may be appropriate.[8]

Safeguarding and strengthening our digital workforce and capability pipeline

Professional mobility

Professional mobility between research, industry and government is an important but currently missing link in the research, innovation and translation ecosystem. Well-rounded professionals—beginning with a well-rounded education and continuing into a range of roles throughout the career course—are the people most likely to turn creative links into successful leaps.

Career progression can often mean leaving professional practice, with the way up the organisational (and salary) ladder being through management. At the same time, generalist managers can have little (or dated) skills in judging technical quality, which can bound their ability to make informed decisions about more cutting-edge research projects.

University hiring and promotion processes often place a strong emphasis on traditional academic publications rather than industry experience and collaborations. In addition, PhD graduates often seek jobs in academia rather than in industry.

Headline recommendation:

11 Universities and publicly funded research agencies reshape their research culture by placing substantially higher emphasis on industry experience, placements and collaborations in hiring, promotion and research funding.

Recommendations:

12 Industry reshape their skills culture by engaging workers in ongoing collaborations with universities and publicly funded research agencies.

13 Encourage joint appointments between government, universities, publicly funded research agencies and industry. Research organisations consider revising employment contracts to assist researchers to take simultaneous employment with businesses.

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6 This could be extended to multi-organisation alliances or collectives of research organisations as proposed in Recommendation 2.

7 This may be Australian or international industry experience.

8 An industry sabbatical scheme could be modelled on the UK College of Engineering's approach that includes a competitive, funded scheme.

Lifelong and work-integrated learning

As the pace of progress increases, jobs in the digital sectors are very likely to involve a substantial proportion of lifelong learning.

Developing the soft skills to work effectively in teams, as well as the metacognitive skills to continue learning and development throughout the working life, is becoming increasingly important. Work-integrated learning, undertaken at scale in Australia, would assist with work-skill development and offer positive cultural changes in both workplaces and the education system.

The Australian higher education sector needs to meet the changing demands of students, governments and employers as digital technology reshapes the social, industrial and workplace landscapes.

Recommendations:

14 Place a greater emphasis on metacognitive skills[9], soft human skills and teamwork in ICT-related teaching at all levels.

15 Incorporate work-integrated learning as a core element of tertiary courses that relate directly to ICT and related engineering subjects.

16 Encourage new PhD graduates to take roles in industry rather than remain in the university sector.

Skills of teachers

Out-of-field teaching, especially in mathematics but also in most sciences, is having a slow-burn effect on our whole education system—the decline being gradual enough as to never warrant attention as an acute crisis, but the effect being just as profound.

Academic qualifications are the primary measure of teacher capability, but valuing industry experience in teachers of ICT-related topics would help them pass on a greater sense of usefulness or relevance to students. At a higher level, PhD supervisors are also often ill-equipped to foster awareness of the human skills and broader context of research in society that is often missing from ICT PhDs.

The loss of the technological colleges that once produced high-quality technicians, who play an important role in the maintenance and operation of key research infrastructure facilities, without replacing that role with suitable training options has added another hurdle.

Recommendations:

17 Australian governments, schools and universities urgently increase their provision of professional development for existing out-of-field school teachers of digitally related subjects in the Australian Curriculum and enhance their commitment to the recruitment and retention of new, properly qualified staff[10].

18 Foster greater awareness in the teaching community and in curriculum materials of the broader impact and implications of digital technologies in society.

Equity and diversity

Realising that Australia cannot reach its full potential unless it can benefit from the talents of all, we have a two-fold responsibility: to increase diversity—particularly women—and to remove structural barriers that cause the loss of knowledge, talent and educational investment from the ICT and engineering sectors.

Attracting high-quality international students to, and retaining them in, Australia after they graduate is a good way to expand the diversity of the ICT skill base and to promote greater international engagement, not least of which with the home countries of those people. We should make it easier to keep such people after the end of their formal studies.

Recommendation:

19 All research organisations accelerate their efforts to address gender imbalance and inclusion through programs such as Athena SWAN. Organisations should develop and track equity and diversity targets or consider focused hiring practices to drive significant and sustained workplace diversity.

Education pathways

Education is a key priority for Australia's digital future: ICT is becoming central to nearly every field of human endeavour. While there are many pathways into an ICT career, the current focus on science, technology, engineering and mathematics (STEM) education in Australia is a positive development that will take time to propagate throughout the system. It must be protected, evaluated and continuously improved over time.

Education pathways in STEM and ICT do not begin at the university front door—they originate in the K–12 years of schooling. This means having quality educational pathways for our youngest people, with parents (at very least influential, if not the, decision-makers) well-informed about the options, pathways and requirements for STEM education and careers.

9 In this case, we take a broad meaning of metacognitive skills as 'skills that help a person learn to learn'.

10 The wording of this recommendation is deliberately consistent with Recommendation 2.1 of the Decadal Plan for Mathematical Sciences, which this plan fully supports: https://www.science.org.au/support/analysis/decadal-plans-science/decadal-plan-mathematical-sciences-australia-2016-2025

Recommendations:

20 Australian governments develop, define and align mechanisms to monitor, evaluate and optimise their ongoing investments to continuously improve Australian STEM education.

21 Develop new models to integrate ICT education into a broad range of fields to draw greater attention to the range of possible pathways into an ICT career.

22 Develop new models that would broaden professional accreditation in Australia to recognise competence rather than solely the completion of a defined training pathway. This can apply to ICT professionals as well as teachers.

Ensuring whole-of-government action for our digital future

Leadership

A whole-of-government commitment to strengthen Australia's digital future is urgently needed, including support for the capabilities that are required and the research and expertise to support them. Australian governments are uniquely placed to provide leadership in a way that multinational companies will not, and universities and SMEs cannot.

Governments themselves need to develop and maintain an appropriate level of content knowledge and technical skills, especially at the more senior levels, in the main policy agencies. While specialist consultants can be called on to fill gaps, they cannot be the default source of advice on critical policy issues.

There can be merit in Australia targeting specific niches where we can lead. However, funders and policy-makers should be encouraged to also make decisions that have longer-term and broader impacts.

Headline recommendation:

23 Undertake a comprehensive national future-readiness review for the Australian digital research sectors, including their links with industry and opportunities to harmonise state, territory and federal initiatives.

Recommendation:

24 Monitor, evaluate and optimise the applied ICT elements of the National Innovation and Science Agenda, including identifying opportunities for its expansion where appropriate.

Proactive policy implementation

Australia needs to be much more proactive about adopting and owning the ICT-driven transformations currently permeating the whole economy. This is also required to place Australia in a position of strength ahead of subsequent waves of change.

Government consultation processes should be genuine and timely and engage all constructive stakeholders. Effective consultation processes can expand the range of perspectives on policy challenges and mitigate the risk of adverse, unexpected consequences.

Policy consistency is also important. Consistency of policy and resourcing enhances our national capacity to realise the dividends of good research by providing academia with the stability required for longer-term research, and industry with more certain investment settings.

Recommendations:

25 Strengthen public commitments around the 'Government as an exemplar' pillar of the National Innovation and Science Agenda[11], and the 'Australia 2030: Prosperity through Innovation' report[12].

26 Promote, support and strengthen the Digital Transformation Agency as a whole-of-government initiative, including support for analogous agencies in all jurisdictions.

Delivering research sector reforms

Intellectual property management in research

Intellectual property (IP) protections are perceived as a greater hurdle by both researchers and industry than as an opportunity. There is a case for standardising some aspects of IP management across all universities as a prerequisite for national solutions that could be uniformly effective. This may include opening some types of IP by default.

Open access data, research and publishing contributes to faster and greater scientific progress. We can all benefit from public good research progress that is not impeded by licencing barriers to uptake.

A number of Australian universities are moving toward open research policies and standard IP licencing to remove arduous negotiations as a barrier to the adoption of knowledge. It can also encourage industry to undertake research in conjunction with the academic community rather than doing it in-house.

11 National Innovation and Science Agenda: https://www.industry.gov.au/national-innovation-and-science-agenda-report

12 Australia 2030: Prosperity through Innovation: https://www.industry.gov.au/data-and-publications/australia-2030-prosperity-through-innovation

Headline recommendation:

27 Develop a position statement on intellectual property across all Australian universities and publicly funded research agencies to remove intellectual property issues as a barrier to research update by industry. The position statement must emphasise the importance of partnerships with industry and recognise the value of intellectual property and cost of research. The position statement should be a first step towards a more comprehensive framework on intellectual property. Where appropriate, universities should be encouraged to promote open IP policies.

Recommendation:

28 Develop a national 'go-to guide' to help companies engage efficiently with IP departments in Australian universities.

Redefining interdisciplinary research

Inter- and cross-disciplinary research can sometimes be taken less seriously by practitioners in the 'pure' disciplines. Yet as digital technology sweeps across the research sector, the early pioneers developing 'digitally transformed research' will change what is currently considered as interdisciplinary work into 'business as usual' research practices. Australia should lead some aspects of this transformation and reap the resulting research leadership rewards.

Interdisciplinary research—both within the sciences and with the social sciences—needs to be valued and not regarded as 'second best'. Similarly, measuring and evaluating research impact has to be broadened to reflect the different types of research, including impacts on other disciplines, sectors and end users.

Research funding agencies such as the ARC and NHMRC rely heavily on traditional academic publications in assessing the track records of grant applicants. This situation disadvantages researchers in industry who are collaborating with researchers in universities, and university researchers who have previously worked in industry.

Recommendations:

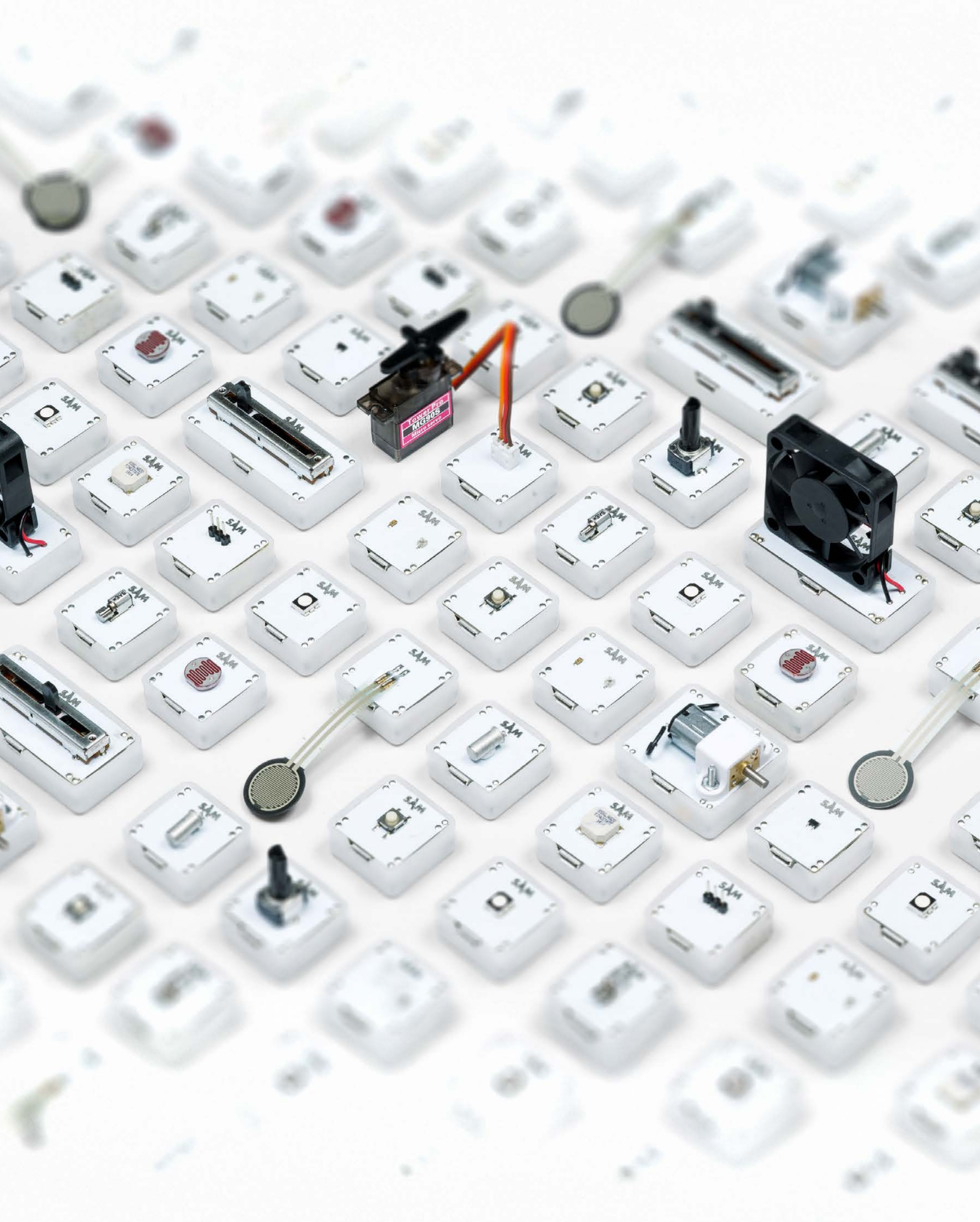
29 Recognising that tomorrow's research leaders will be digitally enabled, Australian universities seek global leadership by proactively pursuing digital research expertise across all disciplines.

30 Reform performance metrics used in ARC and NHMRC research grant proposals so interactions and experience with industry are recognised in ICT-related fields.

31 Reform research funding rules and assessment processes such that interdisciplinary proposals are not disadvantaged.

32 Examine how to quantify the potential of digital technology to transform and accelerate future research across all disciplines, and to underpin interdisciplinary research.

CREDIT: MMISOF / PIXABAY



A collection of SAM Labs modules.
Part of an IOT platform that helps children learn to code

6 Current Australian digital research capability

Digital technology research is a truly international endeavour, and so are the industries that apply it. As such, there can be considerable dividends, and much to learn, by targeted international benchmarking. It also means we can better focus our limited research budget on areas that are likely to have the greatest impact.

This section presents a high-level snapshot of relevant research strengths in Australian universities and research institutions by summarising both the amount and quality of research at a national level[1], using three different windows.

The first window is a direct survey of the online presence of universities and research institutions, to provide an indication of research activity in Australia. This measure relies on self-reporting and assumes the number of groups working in an area (or self-reporting as working in an area) and reflects the amount of research occurring.

The second window is the ARC's research evaluation framework, Excellence in Research for Australia (ERA). While it is an independent measure of the 'quality' of research, it is also limited—for example, it is not tailored to the digital sectors, nor does it indicate commercial impact or innovation translation success.

The third window comes from results extracted from the SCImago Journal & Country Rank[2] and uses publication and citation information contained in the Scopus® database.

Research quantity: self-reported activity

A survey of the websites of all universities and institutions undertaking some form of relevant research was used to collate topic areas where each institution claimed to have a strength.

The existence of a research centre, an institute, or a laboratory or other group of researchers working in a common area was interpreted as signalling a strength in an area. However, individual researchers working alone or in small groups without a significant profile were generally not included, and classified research that is not promoted online was also omitted: this is a limitation of our method.

Raw data was collected across all research institutions in Australia and the number of 'strong' research groups were counted for different research areas across the digital technology sector.

The survey identified:

- 17 strong research groups in data mining, big data, data analytics and visualisation, and in sensor networks, the internet of things (IoT), geolocation and surveillance
- 16 in artificial intelligence (AI) and machine learning (ML)
- 13 in robotics, autonomous and embedded systems
- 11 in modelling, simulation and optimisation
- 10 in wireless and mobile technologies
- 9 each in computation biology, machine–user interfaces, and health analytics
- between 6 and 8 each in areas such as data management and security, optical communications and photonics, quantum devices and computing, and cybersecurity.

Research quality: strengths identified using ERA data

ERA provides a score from 1 to 5 for each university in Australia across all research fields. Eleven research areas using ERA's Fields of Research (FOR) code system were relevant to the present study. All ERA data in those fields were selected and the average taken for the scores of all institutions in Australia in research areas where those institutions received a non-zero score in ERA.

The FOR code system, while providing a useful set of reference data over time, has a number of limitations when used for the current purpose. For example, the codes are

1 As at the end of 2017

2 SCImago Journal & Country Rank: http://www.scimagojr.com

generally quite broad, and researchers must choose a single code that best reflects each funded activity, which means interdisciplinary research may not be completely captured.

Table 2 shows a broad national overview of the average score for each of the 11 FOR codes that relate directly to relevant research.

Table 2. Aggregated data on Australian research quality, reflected in 2016 ERA ratings

Fields of Research code	Average score
0206 Quantum physics	4.66
0103 Numerical and computational mathematics	4.34
0906 Electrical and electronic engineering	4.29
1005 Communication technologies	4.20
0805 Distributed computing	3.67
0801 AI and image processing	3.40
0803 Computer software	3.40
0802 Computation theory and mathematics	3.38
0806 Information systems	3.36
0804 Data format	3.34
1203 Design practice and management	2.86

Research quality: strengths identified using SCImago

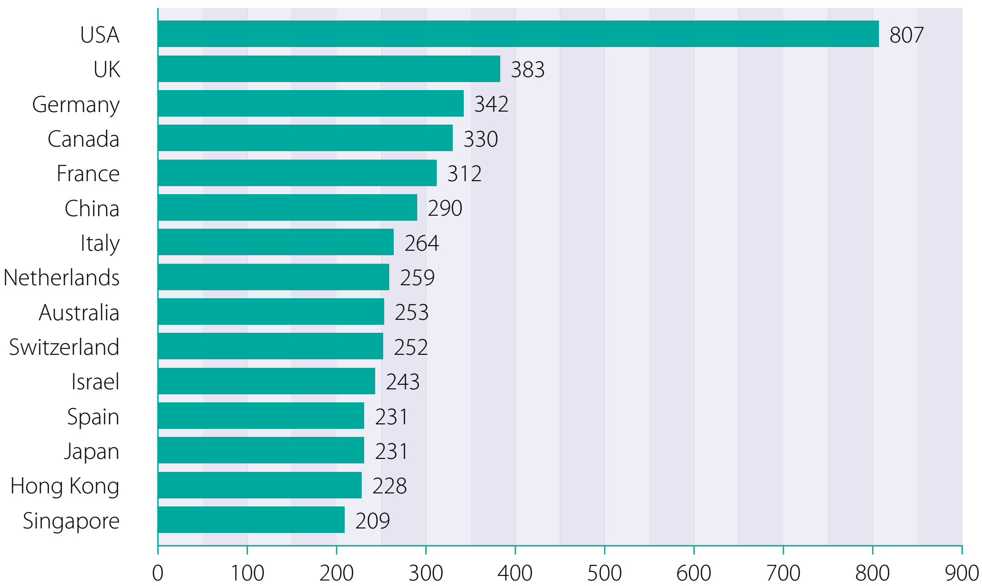
SCImago[3] provides a comprehensive tool for comparing journals and countries across a range of scientific fields and sub-fields. The data covers the period 1996 to 2016 and includes the number of documents, the number of citations, the average number of citations per document, and the H-index. Across all of computer science, the H-index for Australian publications is 253, and Australia ranks 9th in the world.

Figure 1 provides a summary of the H-indexes[4] for the 15 top performing countries across all computer science.

Australia's computer science research is reasonably competitive. All countries ranked above Australia have larger populations than Australia, as do a number of countries ranked below Australia (e.g. Spain and Japan). However, the two countries immediately following Australia in the ranking (Switzerland and Israel) have less than half Australia's population and are relatively very competitive.

With respect to individual research areas, Australia ranked 7th in information systems, signals processing, and hardware and architecture; 8th in human–computer interactions, computer networks and communication, computer science applications, and computation theory and mathematics; and 10th or below in software, computer vision and pattern recognition, and artificial intelligence.

Figure 1. Country rankings by H-index across all of computer science



3 SCImago Journal & Country Rank: http://www.scimagojr.com

4 A metric designed to measure the citation impact and the productivity of the publications of a particular scholar or scientist; also sometimes referred to as the Hirsch-index or -number

Research quality and quantity: a national overview

There is insufficient information to provide definitive answers at a fine scale about the quality and quantity of Australian research in ICT.

Complaints from the business and government sectors, and even academics, regarding the difficulty of finding relevant research capability in Australia appear to be well-founded. There appears to be a strong case to undertake a characterisation of ICT-related research in Australia, mapped to industry and business needs to identify potential strengths and gaps.

Nevertheless, in broad terms, Australia has existing research strengths in many areas. There are significant strengths (both in quantity and quality) in:

- quantum devices and computing
- data mining, big data, data analytics and visualisation
- sensor networks, the internet of things, geolocation and surveillance
- modelling, simulation and optimisation
- wireless and mobile
- robotics, autonomy and embedded systems
- artificial intelligence and machine learning.

Current Australian digital workforce capability

Digital technologies are inherently international and are shaped much more strongly by global rather than local influences. Being relatively less sensitive to local actions, there are limited ways in which industry, government and training providers can intervene in this sector to create local impacts[5].

Just over one half (52 per cent) of the current ICT workforce is employed outside of directly ICT-related industries. Among the top destinations for IT graduates in Australia are health care and social assistance; transport, postal and warehousing; manufacturing; wholesale trade; and retail trade.

Clearly, IT graduates are propagating throughout the Australian economy. As the proportions of IT-qualified workers increases in any given field or economic sector, it would be expected those fields or sectors would develop the capability to lead ICT-driven transformations and to rapidly adopt advances from overseas.

While employers are demanding a range of ICT-specific skills, there is also increasing demand for ICT workers with more general skills. Generic ICT skills and 'digital literacy' have also emerged as highly desired skills for jobs across the economy. They are also central to the process of learning, as primary, secondary and tertiary educational institutions increasingly utilise technology in the delivery of educational programs.

The Australian Workforce and Productivity Agency's ICT Workforce Study[5] also noted that our workforce supply side is experiencing a range of challenges, including the ICT industry carrying a legacy of negative perceptions of desk-bound, repetitive, isolating jobs; skills supply being limited by the low levels of female and mature-aged workers in the ICT workforce; and many students who pursue an ICT education experiencing difficulty in finding employment in the sector upon graduation, with many graduates using their qualifications to pursue careers outside ICT.

Other challenges include employers complaining that tertiary graduates do not possess the desired combination of technical and complementary business and communication skills to contribute effectively in the workplace and, despite the increasing complexity of ICT services and the growing demand for these skills, the engagement and investment of industry in ICT skills development remains low.

Nevertheless, a number of potential solutions are available, such as changing and improving perceptions of ICT careers; improving the quality of ICT teaching in schools and tertiary education institutions, and exciting students about ICT careers; improving the suitability of tertiary graduates for entry-level positions; increasing the number of workers with ICT-intensive skills; increasing the number of workers with the functional knowledge of ICT required to work with ICT specialists; and ensuring employers of ICT workers, including employers of ICT contractors, support ongoing skills development and the effective utilisation of skills in a fast-moving and rapidly changing sector.

5 Australian Workforce and Productivity Agency, 2013: ICT Workforce Study: https://docs.education.gov.au/system/files/doc/other/ict-workforce-study-2013.pdf

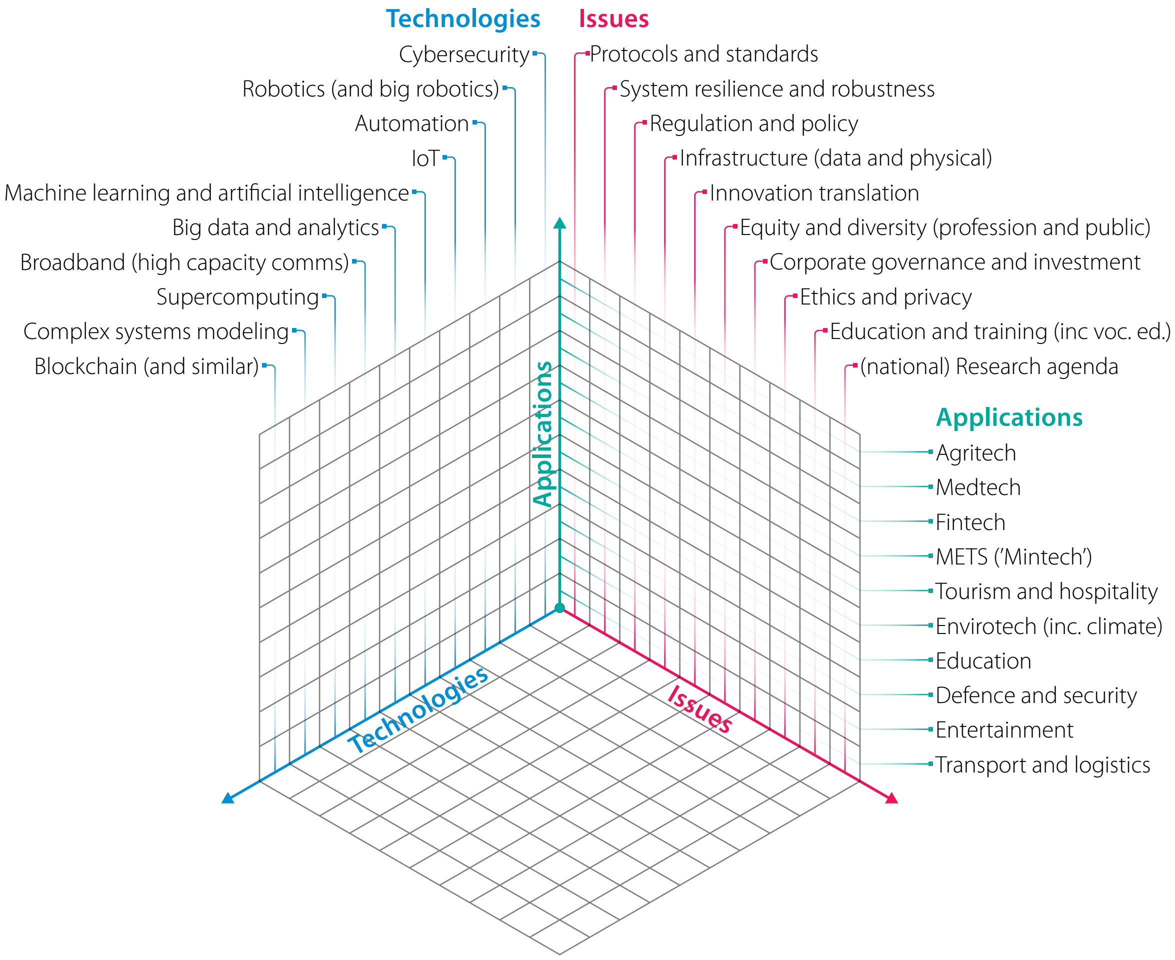
A blockchain network of 1.4 million wallets, connected by 2.6 million payment relationships—all connected visually in a complex network graph. This visualisation represents the full XRP cryptocurrency ledger at mid-November 2018.

CREDIT: THOMAS SILKJÆR ©

7 A model framework

A simple model to visualise the interconnected nature of the digital and digitally enabled sectors is to plot enabling technologies, application areas and issues on orthogonal axes[1]. The resulting three-dimensional space provides a useful framework that immediately reveals the breadth of considerations this strategic plan attempts to address—as well as the lack of information on many of them. Interconnections within and between the technologies, applications and issues can be visualised as surfaces in this space.

Figure 2. A model framework for considering the interconnected nature of digital technologies, their applications and their implications



Note that the actual technologies, applications and issues provided in this example are not absolute and can be added to or subtracted from the model to meet the needs of the model user

1 The axes and the position of each item on each axis are arbitrary: unconscious biases about the x, y, and z axes should be confronted for the sake of ignoring them

Using the framework

The integrated framework makes clear the interconnectedness of the reach of digital technologies throughout our lives and our economy.

The framework can be reduced to a series of matrices. For example, looking parallel to the application axis from the perspective of agritech results in a matrix of technologies that could be applied in agritech and issues to consider from an agricultural perspective.

Looking from the perspective of big data analytics (an enabling technology) we see a matrix of possible applications and the issues to consider. Looking from the perspective of a particular issue yields a matrix of the applications that may be affected by that issue and the technologies that could be relevant.

The applications perspective

Looking at the framework from the perspective of a specific application (looking parallel to the z axis as shown) may be useful for industry participants whose business is focused on a particular application (e.g. a pharmaceutical company will mostly be interested in medtech) and who may wish to more effectively tackle the issues facing that application or look for other technologies that may be relevant. It may be useful to governments when specific industries are of policy interest or to inform sector-specific policies (e.g. to help consider interplay between agricultural policy and the National Broadband Network).

The technology perspective

Looking at the framework from the perspective of a certain technology (looking parallel to the y axis as shown) may be useful for researchers who are interested in shaping their research direction based on the presence (or absence) of realistic uptake pathways, or to identify possible applications and perhaps additional investors or funding sources that may not have otherwise been considered. Thinking inside the box, the framework can also help place research in context for grant applications.

It can also be useful for higher education providers: curriculum development could be informed by considering how each technology links with industry and society, and for holders of patents for a specific technology; systematically exploring potential uses, opportunities for innovation translation, potential barriers to uptake or conflicting societal influences may improve the success rate of attempts to translate research into commercial success.

The enablers/issues perspective

Looking at the framework from the perspective of a certain issue, be it a specific enabling factor, a barrier or even a social or political trend (looking parallel to the x axis as shown) may be useful for governments and policy-makers who need to examine issues affecting (and affected by) digital technologies in the context of the whole sector, to help identify linkages (synergies or conflicts) with other policies, as well as any application areas that may provide key stakeholders (likely allies or opponents).

It can also be useful for science communicators interested in human-centred communication: communicating the issues that matter to people and their many implications is an alternative and highly effective approach to the traditional view of science communication as filling an assumed 'knowledge deficit'; and economic or social assessments: the framework provides another tool with which to ensure the completeness of factors considered in assessments or studies.

Avoiding single perspectives

Industry participants, governments and researchers can readily use a different perspective from somebody else's perspective to gain a deeper understanding of the system in which we all operate and interact. Such understanding is especially helpful when collaborating across sectors and interacting with other people or organisations that may hold different motivations, experience different pressures or have different performance indicators.

8 Implementation plan

The implementation of the recommendations in this plan will depend on the prompt establishment of a taskforce, which will also monitor future progress. The taskforce should consider the following roles in its terms of reference:

- investigating a mechanism by which the priorities in this plan can be adopted by Australian Government agencies, such as the Office of the Chief Scientist and Innovation and Science Australia, as well as state governments
- approaching key organisations and active contributors to present the case for recommendations that apply to them
- reporting back to the academies on progress made (i.e. whether the recommendations have or have not been implemented and the associated impacts or lost opportunities)
- taking an active role in the annual review of research competencies (tentative).

The taskforce will also need to commence implementing the specific recommendations and develop concrete actions that form the 'next level down' from the general recommendations in this plan.


MACH4

Appendix 1 An overarching framework for a complex digital environment

Despite the amount of good work underway across Australia, we lack an overarching framework to help (metaphorically) map the terrain. A framework that encourages us to think about the digital realm as a complex and interconnected system is proposed because digital technologies have become so pervasive that everything—from data theory to new hardware to primary school education—is now inter-linked.

In the best-case scenario, tackling any aspect of our digital future in isolation can be effective only in a small, and perhaps isolated, domain. In a more common scenario, a new initiative can be only partially effective in a small domain because issues or barriers that were 'out of scope' were not considered. In the worst-case scenario, well-intentioned activities in one area can be counterproductive overall.

New technologies, application areas and technical or societal issues arise from time to time. An inclusive, non-prescriptive framework provides an efficient way to assess the potential impacts and flow-on effects of a change, be it a new societal driver, a new policy direction or a new technology development; and identify which other technologies, applications or issues could provide useful knowledge or experience to help avoid any problems with uptake or to make it easier for existing systems to accommodate change/progress (both IT systems and socio-economic-cultural systems).

The framework developed in support of this strategic plan helps to address these points by providing a way of visualising—or at least organising for systematic consideration—the many connections between the applications of digital technology, the technologies themselves, and the many issues that the technology either faces or raises for others. This framework uses the word 'issues' in a neutral sense to describe a spectrum that ranges from 'enabling factors' through to 'barriers', which apply equally to technological as well as socio-economic issues. No firm distinction is drawn between enabling factors and barriers because of the interconnected nature of the framework—the same issue can be both an enabling factor and a barrier depending on the angle you view it from.

Each of the underpinning technologies, application areas and issues are summarised in the following sections.

Underpinning technologies

This section lists some of the many underpinning technologies rather than attempting to describe them in detail. Part of the utility of the proposed framework is its ability to recognise and adopt the very large volume of work already undertaken, rather than require reinterpretation or duplication. This list is not comprehensive; technologies can be added or subtracted to the framework as required:

- machine learning and artificial intelligence
- cybersecurity
- automation and robotics (and big robotics)
- internet of things (IoT)
- big data and analytics
- data visualisation
- broadband (high capacity communications)
- high-performance computing (HPC)
- quantum computing
- complex systems modelling
- blockchain (and similar)
- sensor technologies.

Application areas for digital technologies

Among the array of possible applications of digital technologies are:

Agritech—examples include:

- geolocation
- remote monitoring and telemetry
- IoT
- weather and climate modelling
- genome-wide association studies (GWAS), HPC
- deep learning/image recognition
- automation and robotics
- protected cropping
- big data.

Medtech—examples include:

- automation, robotic-assisted care, robotic care
- deep learning and diagnosis
- patient medical records
- GWAS, big data, HPC
- drug and vaccine design
- epidemiology and population health
- wearables and sensors
- social media analytics
- remote health care.

Fintech—examples include:

- quantum encryption
- blockchain and similar ledgers
- market analyses: AI and big data
- non-traditional financial information
- personalised pricing
- rapid transactions
- anonymity, intelligence, law enforcement.

METS and MinEx (together 'Mintech')—examples include:

- industrial automation
- geological big data
- data fusion, inversion, AI
- HPC
- in-field sensors, remote sensing
- automation of exploration.

Tourism and hospitality—examples include:

- automated reception and service
- personalised service
- location-sensitive information availability
- virtual experiences (virtual reality (VR) and augmented reality (AR))
- new services.

Envirotech (including climate)—examples include:

- automation of environmental monitoring
- new and cheaper sensors, distributed networks
- big data, non-traditional information sources, data fusion, AI
- machine vision and object/event identification
- Earth observation satellites
- in-situ or inaccessible analyses
- real-time, high bandwidth communication
- real-time reporting
- meeting international obligations.

EdTech (Education)—examples include:

- technology in schools
- predicting future skill sets
- shorter attention spans
- symbolic logic from an early age
- higher education as a service industry
- emerging ecosystem of education and information sources
- pedagogic focus versus skills and capability focus
- accelerating pace of change.

Defence and security—examples include:

- persistent and automated surveillance
- blurring line between defence and national security
- threats also undergoing a technology revolution
- non-traditional intelligence sources
- big data, data integration in real time
- enhanced humans (sensing capability, information processing capacity, mobile decision support systems, mechanical assistance)
- emergency management systems.

Entertainment, social media and gaming—examples include:

- music and TV already transformed to on-demand
- social media
- smartphone as primary browsers
- gaming
- navigation and driving
- IoT modifying behaviour
- AR/VR just in its infancy
- both driver and beneficiary of tech development (e.g. camera sensors, gaming GPUs)
- gaming machines used in research, gaming engines used in data visualisation
- big data, AI, personalisation, privacy.

Transport and logistics—examples include:

- ubiquitous connectivity
- new services
- (semi)autonomous transport (all modes)
- efficient logistical planning
- emergency management of whole systems
- big data, data integration in real time
- real-time traffic management/route optimisation.

Issues: enabling factors or barriers affecting the digital sectors

As previously mentioned, this framework uses the word 'issues' in a neutral sense to describe a spectrum that ranges from 'enabling factors' through to 'barriers' which apply equally to technological as well as socio-economic issues. No firm distinction is drawn between enabling factors and barriers because of the interconnected nature of the framework—the same issue can be both an enabling factor and a barrier depending on the angle you view it from.

Protocols and standards

Policy, protocols, standards and regulation can act as both enablers and barriers. Particular issues in this category include:

- cybersecurity
- interoperability
- data reuse
- mitigation of technology lock-in and adoption of new technologies.

System resilience and robustness

Resilience and robustness can act as both enablers and barriers to technology uptake. Particular issues in this category include:

- failure modes (including the unexpected)
- whole-of-system vulnerability
- how systems respond when they fail
- how people respond when systems fail
- system fragility as a strong barrier to uptake
- validation (before or after deployment)
- hardware robustness and critical sensors.

Regulation and policy

Policy settings can encourage innovation and uptake or inhibit it. A small selection of the issues in this category include:

- protection of privacy
- income inequality
- universality of internet access
- net neutrality
- business, competition, IP, innovation policy settings.

Infrastructure (data and physical)

Infrastructure of all kinds is often a key enabler or barrier. Issues in this category include:

- common platforms for data and information exchange
- data infrastructure for research and society
- digitally prepared physical infrastructure.

Innovation translation

Translation of innovation into commercial success is a topical issue in Australia. Refer initially to:

- Innovation and Science Australia, 2016. Performance Review of the Australian Innovation, Science and Research System
- Innovation and Science Australia, 2018. Australia 2030: Prosperity through Innovation: A plan for Australia to thrive in the global innovation race.

Equity and diversity (professional and public)

Issues relating to equity and diversity can act as both enablers and barriers to technology uptake, as well as to societal well-being more generally. Issues in this category include:

- gender and social equity
- economic impact of poor retention and career progression: wasted training, lost productivity
- benefits of diversity
- numerous potential drivers of income inequality
- avoiding a new class system based on access to information and technology.

Corporate governance and investment

Issues related to corporate governance can act as both enablers and barriers, although it should be noted that failure receives public attention and success is often quiet. Issues in this category include:

- research funding
- incentives for collaboration between researchers and end-users
- greater access to venture capital.

Ethics and privacy

Issues related to ethics and privacy can act as both enablers and barriers, although it should similarly be noted that successful management of these issues goes unnoticed by the public. Issues in this category include:

- use of technology to harvest personal information
- security of retained metadata
- public awareness of and attitudes towards default privacy settings
- attitudes differ by age and profession
- encoding ethics into AI
- ethics of autonomous systems engaging directly with humans
- ethics of autonomous systems making decisions that affect humans.

Education and training

Education is Australia's existing area of strength, yet it also faces issues that could act as both barriers and enablers.

School education—including:

- ensuring basic capabilities in statistics and data
- improving the quality of pre-service teacher training
- ensuring students are competent and comfortable adopting, adapting and implementing new and existing technologies in the context of workforce changes and transformations.

Vocational education and training—including:

- technical skills required to manage and maintain emerging digital technologies and applications.

University education—including:

- enhancing graduate employability through internships or other mechanisms
- aligning course design with industry needs
- ensuring graduates are equipped with the attributes that will be required to continue participating/leading as the pace of change accelerates into the future
- changing the expectations of both students and employers (information and communication sciences (ICS) and ICT graduates may not end up employed where they thought they would be yet bring skills that are no less useful in those other areas)
- achieving greater diversity and gender balance in ICS and ICT higher education, which underpins the above points.

Workforce pathways and career development—including:

- facilitating mobility between research, industry and government sectors
- diversity and gender balance among ICT professionals
- facilitating collaboration between universities, industry and governments.

CREDIT: ECHO GRID / UNSPLASH

Appendix 2 The Australian ICT research and innovation sector: preliminary status assessment

Many policies and programs constitute 'Australia's position' on issues related to information and communications science, engineering and technology. This section provides a brief outline of some of them.

National Science and Research Priorities

The National Science and Research Priorities[1] are reviewed every two years: currently they are food, soil and water, transport, cybersecurity, energy, resources, advanced manufacturing, environmental change, health.

While cybersecurity is the only priority that is directly within the scope of ICT, the underpinning capability that is provided across the board by the digital sector must not be forgotten.

National Innovation and Science Agenda (NISA)

The National Innovation and Science Agenda comprises four key pillars, collectively worth $1.1 billion over four years[2], namely:

- providing tax breaks for business
- refocusing university funding towards industry collaboration
- STEM education and visa reforms[3], to develop and attract the right skills to Australia
- reforming government to lead by example.

The Agenda also coordinates several new and existing programs managed by a range of agencies.

Note that various state governments also have active STEM education programs; NSW[4] and Victoria[5] provide notable examples.

National Collaborative Research Infrastructure Strategy (NCRIS)

The 2016 National Research Infrastructure Roadmap[6] outlines the future direction of NCRIS[7], which drives research excellence and collaboration between government, industry and 35 000 researcher to deliver practical outcomes.

One of the most significant changes envisaged by the 2016 Roadmap is the merger of the digital and eResearch NCRIS facilities (the Australian National Data Service (ANDS), the National eResearch Collaboration Tools and Resources project (Nectar) and Research Data Services (RDS)) into a single National Research Data Cloud. This merger is ongoing[8].

Commonwealth Science Council

The Commonwealth Science Council[9] provides strategic advice to government on science and technology issues and building stronger collaboration between scientists, researchers and industry. The Council is Chaired by the Prime Minister, with the Minister for Industry, Innovation and Science as Deputy Chair. Australia's Chief Scientist, Dr Alan Finkel, is the Executive Officer.

1 National Science and Research Priorities: https://www.industry.gov.au/data-and-publications/science-and-research-priorities

2 Australian Government National Innovation and Science Agenda: https://www.industry.gov.au/strategies-for-the-future/boosting-innovation-and-science

3 Administered by the Department of Education: https://www.education.gov.au/inspiring-all-australians-digital-literacy-and-stem

4 STEM-NSW: http://www.stem-nsw.com.au

5 VicSTEM: http://www.education.vic.gov.au/about/programs/learningdev/vicstem/Pages/default.aspx

6 Department of Education and Training 2016: https://www.education.gov.au/2016-national-research-infrastructure-roadmap

7 Department of Education and Training: https://www.education.gov.au/national-collaborative-research-infrastructure-strategy-ncris

8 Current updates may be available at: https://www.ands-nectar-rds.org.au

9 Commonwealth Science Council: http://www.chiefscientist.gov.au/commonwealth-science-council/

Innovation and Science Australia

Innovation and Science Australia[10] is an independent statutory board established in October 2016, with responsibility for providing strategic whole-of-government advice to the Australian Government on all science, research and innovation matters. The Board complements the Commonwealth Science Council.

Innovation and Science Australia conducted a Performance Review of the Australian Innovation, Science and Research System[11] and followed up with the report: Australia 2030: Prosperity through Innovation[12], which was intended to serve as a strategic plan for the Australian innovation, science and research system.

Digital Transformation Agency

The Digital Transformation Agency[13] is a government-focused entity intended to make it easy for people to deal with government, by helping government transform services to be simple, clear and fast. It recently developed a Digital Service Standard[14] to aid in its mission.

Department of Industry, Innovation and Science

Office of the Chief Scientist

Among other roles, the Office of the Chief Scientist provides various benchmarking and other analyses of STEM education and workforce development in Australia, including a Position Paper on Science, Technology, Engineering and Mathematics in the National Interest: A Strategic Approach[15] and advice to governments (to provide an evidence base for policy development)[16].

The Office of the Chief Scientist managed the development of the National Research Infrastructure Roadmap.

The current Chief Scientist has also been a vocal contributor to the public discourse on technologies such as AI and other issues related to Australia's digital future[17].

Cooperative Research Centres Program

AusIndustry manages the Cooperative Research Centres (CRC) Program[18], which is a competitive, merit-based grant program that supports industry-led and outcome-focused collaborative research partnerships between industry, researchers and the community. It also supports CRC Projects for short-term, industry-led collaborative research.

Industry Growth Centres Initiative

The Industry Growth Centre Initiative 'enables national action on key issues such as collaboration, commercialisation, international engagement, skills and regulation reform'[19]. As such, Growth Centres are capable of simultaneously addressing research, development, education and policy/regulatory considerations—the broad suite of considerations beyond the science and research that are the focus of this report.

Growth Centres appear to be based on sound policy principles, yet feedback is mixed about the actual impact—ranging from highly effective to unclear value for money. Program design varies considerably from centre to centre, and good design is important. The current six Growth Centres under the NISA are far too early in their life cycle to evaluate, but experience from the US and UK show ICT-related centres can be effective. As a general rule, the better-defined the industry the more effective the IGC.

The authors of this plan were not able to determine the procedural rigour of the process for deciding the current six Growth Centres yet note that the decision to include a cybersecurity IGC in the current suite was underpinned by a trusted evidence base in the form of Australia's 'cyber security strategy'[20] and cybersecurity is an identified National Science and Research Priority[21].

The role of Growth Centres in accelerating specific aspects of the wider digital research, development and industry space has clear potential that should not be limited to cybersecurity. However, Growth Centres appear to be effective over a

10 Innovation and Science Australia: https://www.industry.gov.au/strategies-for-the-future/innovation-and-science-australia

11 Innovation and Science Australia: https://www.industry.gov.au/sites/default/files/2018-10/performance-review-of-the-australian-innovation-science-and-research-system-isa.pdf

12 Innovation and Science Australia: https://www.industry.gov.au/data-and-publications/australia-2030-prosperity-through-innovation

13 Digital Transformation Agency: https://www.dta.gov.au

14 Digital Transformation Agency: https://www.dta.gov.au/standard/

15 Office of the Chief Scientist 2013: http://www.chiefscientist.gov.au/wp-content/uploads/STEMstrategy290713FINALweb.pdf

16 Office of the Chief Scientist: http://www.chiefscientist.gov.au/advice-to-government/

17 See, for example: https://theconversation.com/finkels-law-robots-wont-replace-us-because-we-still-need-that-human-touch-82814 and https://theconversation.com/finkel-overcoming-our-mistrust-of-robots-in-our-homes-and-workplaces-96787

18 AusIndustry: https://www.business.gov.au/assistance/cooperative-research-centres-programme

19 Industry Growth Centres: https://industry.gov.au/industry/Industry-Growth-Centres/Pages/default.aspx

20 Australia's Cyber Security Strategy: https://cybersecuritystrategy.pmc.gov.au/assets/img/PMC-Cyber-Strategy.pdf

21 Australia's Science and Research Priorities: http://www.science.gov.au/scienceGov/ScienceAndResearchPriorities/Pages/default.aspx somewhat narrower scope than this plan describes. Growth Centres could be particularly effective when employed as a combination of:

- a coordinated series of Growth Centres
- the integration of ICT-intensive innovation into each of the current (and all future) Growth Centres, to accelerate Australia's digitally enabled transformation across all sectors.

Business Research and Innovation Initiative (BRII)

Under the NISA, the Department of Industry, Innovation and Science administered a pilot program[22] to encourage businesses to develop more innovative solutions to government policy and service delivery problems, rather than simply procuring them.

Incubator support

AusIndustry administers an incubator program[23] to help new businesses establish and grow.

Global Innovation Strategy

The Global Innovation Strategy[24] brings a range of internationally focused initiatives together, including:

- 'Landing Pads' in five international cities to provide market-ready startups with a short-term (90 day) operational base
- seed funding to support global SME-to-researcher collaborations to enable viable projects to grow and test commercialisation through the Global Connections Fund
- funding to assist Australian businesses and researchers to collaborate with global partners on research and development projects through the Global Innovation Linkages program
- building regional linkages in the Asia-Pacific through the Regional Collaborations Programme.

Productivity Commission

The Productivity Commission has undertaken a considerable amount of research on digital issues in the Australian economy, including two major recent research papers:

- Digital Disruption: What do governments need to do?[25]
- Data availability and use[26]. (A cross-agency taskforce recently delivered the Government's response to this report[27].)

Numerous submissions made by the Productivity Commission to various inquiries also provide detailed analyses of the effects (and potential) of AI, big data and other digital technologies on the Australian economy.[28]

Department of Health and the Australian Digital Health Authority

The Department of Health and the Australian Digital Health Authority champion Australia's National Digital Health Strategy[29].

Department of Infrastructure and Regional Development

The Department of Infrastructure and Regional Development is responsible for land transport reform and will be foundational to the development of autonomous transport systems in Australia—one of the highest profile digital transformations expected in the next decade. It currently supports this role through international engagement and has also, together with state and territory governments, supported the development of the iMOVECRC[30].

Department of Education

Digital technologies

The Department of Education administers a range of digital technologies initiatives[31] to provide Australian teachers support to prepare students for the challenges of the digital economy.

Australian Digital Technologies Challenges

The Australian Government is funding the Australian Digital Technologies Challenges for Year 5 and 7 students. The University of Sydney is developing an online series of 18 free, structured, progressive teaching and learning activities and challenges for all Year 5 and 7 students, aligned to the

22 Business Research and Innovation Initiative: https://www.business.gov.au/assistance/business-research-and-innovation-initiative
23 AusIndustry: https://www.business.gov.au/assistance/incubator-support
24 Department of Industry, Innovation and Science: https://www.industry.gov.au/strategies-for-the-future/increasing-international-collaboration
25 Productivity Commission 2016: https://www.pc.gov.au/research/completed/digital-disruption
26 Productivity Commission 2017: https://www.pc.gov.au/inquiries/completed/data-access#report
27 Australian Government 2018: http://dataavailability.pmc.gov.au
28 See, for example: http://www.pc.gov.au/research/supporting
29 Australia's National Digital Health Strategy: https://www.digitalhealth.gov.au/australias-national-digital-health-strategy
30 iMOVECRC: https://imovecrc.com
31 Australian Government Department of Education: https://www.education.gov.au/inspiring-all-australians-digital-literacy-and-stem

Australian Curriculum. The initiative includes lesson plans, professional learning and online support for teachers, and is funded to 2020. The first four challenges are now available on the Australian Computing Academy[32].

Education Council

All states and territories have endorsed a nationally agreed STEM education policy[33].

Learned academies

The Australian Academy of Technology and Engineering[34] administers the Global Connections Fund[35], which aims to provide initial funding support to promote Australian researchers and SME collaboration.

The Australian Academy of Science[36] administers the Regional Collaborations Programme[37], which aims to fund Australian participants from eligible organisations to collaborate with regional and international science, research and innovation partners on solutions to shared regional challenges within the Asia–Pacific region.

The Australian Research Council

ARC Linkage

The ARC Linkage program helps link university research with industry[38].

Research impact assessment

The ARC ran a pilot research impact assessment in mid-2017. The measures that were tested were reviewed ahead of the first full national assessment in 2018[39]. Using the ERA to generate impact and engagement narratives from universities is a welcome reform towards broadening the academic performance metrics to recognise research–industry collaboration.

CSIRO

Besides engaging directly in industry-relevant research as part of its charter, CSIRO runs several programs relevant to cybersecurity, AI and ML, and to facilitating the digital changes that society is experiencing.

CSIRO Innovation Fund

The CSIRO Innovation Fund is a joint government–private sector fund intended to help Australia's home-grown innovations become successful businesses[40].

CSIRO ON accelerator program

CSIRO ON[41] is an innovation accelerator program that intends to discover innovative research that addresses industry-related challenges in food and agriculture, advanced manufacturing, medical technologies, cybersecurity, mining technology and energy. It then aims to steer research towards high-potential innovative ventures.

Data61

CSIRO's Data61[42] is Australia's leading data innovation group which was officially formed in 2016 from the integration of CSIRO's Digital Productivity flagship and the National ICT Australia Ltd (NICTA). Its mission is to create Australia's data-driven future.

Policy statements and administrative arrangements

Australian Government Public Data Policy Statement

The Australian Government Public Data Policy Statement was published in December 2015. Australian Government entities are now required to make appropriately anonymised, non-sensitive data open by default[43].

The Digital Marketplace

The Digital Marketplace is an ecosystem where government buyers can publish briefs with their requirements, suppliers can respond, and two-way collaboration can take place.

The Marketplace[44] is intended to provide an alternative model of government procurement, in which suppliers can pitch creative ideas to solve problems. This provides businesses the chance to develop innovative digital solutions for government and allows two-way collaboration to occur.

AI-based decision-making

A large number of decisions that were previously made by ministers or their delegates in the bureaucracy are explicitly allowed by legislation to be delegated to machines.

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32 Australian Computing Academy: https://aca.edu.au

33 Education Council 2015: http://www.educationcouncil.edu.au/site/DefaultSite/filesystem/documents/National%20STEM%20School%20Education%20Strategy.pdf

34 Australian Academy of Technology and Engineering: https://www.applied.org.au

35 Global Connections Fund: https://globalconnectionsfund.org.au

36 Australian Academy of Science: https://www.science.org.au

37 Australian Academy of Science: https://www.science.org.au/regional-collaborations-programme

38 Australian Research Council Linkage Program: http://www.arc.gov.au/linkage-projects

39 Australian Research Council: https://www.arc.gov.au/engagement-and-impact-assessment/ei-pilot-overview

40 CSIRO Innovation Fund: https://www.csiro.au/en/news/news-releases/2018/csiro-innovation-fund-boosts-jobs-and-innovation

41 ON:Innovation: http://oninnovation.com.au

42 Data61: http://www.data61.csiro.au

43 Department of the Prime Minister and Cabinet: https://www.pmc.gov.au/resource-centre/public-data/australian-government-public-data-policy-statement

44 Digital Marketplace: https://marketplace.service.gov.au/

According to the ABC, there are 29 pieces of enabling legislation[45], although their consistency with the Australian Government's recent Digital Service Standard has not yet been established.

Parliamentary activities

A number of current and completed Parliamentary Inquiries[46] may also provide useful background, considering they (and their submissions) also serve as a record of public views at the time of each inquiry.

The Parliamentary Joint Committee on Law Enforcement conducted an inquiry on 'the impact of new and emerging information and communications technology (ICT)'[47].

Its Terms of Reference are:

- challenges facing Australian law enforcement agencies arising from new and emerging ICT
- the ICT capabilities of Australian law enforcement agencies
- engagement by Australian law enforcement agencies in our region
- the role and use of the dark web
- the role and use of encryption, encryption services and encrypted devices
- other relevant matters.

State and territory government initiatives

Most state and territory governments have active programs and policies that relate, directly or indirectly, to the digital transformations that are forecast for Australia.

Other initiatives

A number of initiatives have not been covered in this assessment but should also be considered, including:

- Innovation Connections: connecting industry to innovation infrastructure[48]
- Innovation in agriculture and regional areas[49]
- Inspiring all Australians in STEM[50]
- Intangible asset depreciation[51]
- Science in Australia Gender Equity (SAGE).[52]

45 ABC News: http://www.abc.net.au/news/2017-07-21/algorithms-can-make-decisions-on-behalf-of-federal-ministers/8704858

46 Parliament of Australia: https://www.aph.gov.au/Parliamentary_Business/Committees/Current_Inquiries#fndtn-tabSenate_Committees

47 Parliament of Australia: https://www.aph.gov.au/Parliamentary_Business/Committees/Joint/Law_Enforcement/NewandemergingICT

48 Innovation Connections: connecting industry to innovation infrastructure: https://www.industry.gov.au/strategies-for-the-future/boosting-innovation-and-science

49 Innovation in agriculture and regional areas: https://www.industry.gov.au/strategies-for-the-future/boosting-innovation-and-science

50 Inspiring all Australians in STEM: https://www.education.gov.au/support-science-technology-engineering-and-mathematics

51 Intangible asset depreciation: https://www.industry.gov.au/strategies-for-the-future/boosting-innovation-and-science

52 Gender equity in STEM: http://www.sciencegenderequity.org.au


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